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U. S. DEPARTMENT OF THE INTERIOR

GEOLOGIC INVESTIGATIONS IN SUPPORT OF PROJECT CHARIOT, PHASE III, IN THE VICINITY OF CAPE THOMPSON, NORTHWESTERN ALASKA

Preliminary Report

By

Reuben Kachadoorian, Russell H. Campbell, George W. Moore, David W. Scholl, Arthur H. Lachenbruch, Gordon W. Greene, B. Vaughn Marshall, David F. Barnes, Rex V. Allen, Roger M. Waller, Marvin J. Slaughter

January 1961

This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

Geological Survey
Washington, D. C.

Prepared by Geological Survey for the
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Office of Technical Information

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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Trace Elements Investigations Report 779

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*Prepared on behalf of the U. S. Atomic Energy Commission

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ABSTRACT AND GENERAL INTRODUCTION

By

Reuben Kachadoorian

Abstract

The Chariot test site, at the mouth of Ogotoruk Creek in the vicinity of Cape Thompson, Alaska, is geologically and topographically well situated for the detonation of several nuclear devices to create an experimental excavation proposed by the U. S. Atomic Energy Commission.

In the area within a 15-mile radius of the Chariot test site, bedrock consists entirely of consolidated clastic and chemical sediments, probably all of which were deposited in marine environments. The rocks range in age from Early Mississippian to Cretaceous(?), and the total thickness is estimated to be at least 23,700 feet. The rock units crop out in north-trending bands with the oldest rocks exposed on the west side of the area and progressively younger beds exposed across the area from west to east. Older rocks, of probable Devonian age, are exposed to the northwest of the mapped area.

In the western half of the 15-mile semicircular area, the structure is dominated by a series of imbricate thrust faults, along each of which sheets of limestone and dolomite of the Lisburne group of Mississippian age have been thrust eastward. In the eastern half of the area the rocks are complexly folded and broken by high-angle faults. Virtually all of the structure was probably formed during the Laramide orogeny. The differences in structure between the two parts of the area probably reflect the difference in response to the deforming stresses by rocks of different competence. The competent rocks of the Lisburne group moved eastward in thrust sheets as the less competent mudstone and sandstone of the Jurassic-Cretaceous, and Cretaceous(?) units were intricately crumpled. The structure is interpreted as resulting from gravitational gliding down an east-dipping basement slope--the western limb of a large north-trending syncline with an axis near Cape Seppings.

The Chariot test excavation lies entirely in frozen mudstone which has been complexly folded and faulted. Locally, the rocks are overturned. The mudstone contains numerous fault zones, most of which are less than 5 feet wide, with the exception of a 14.3-foot fault zone in Hole Baker and an 8-foot zone in Hole Charlie. The strike of the mudstone averages N. 20° E. and the most common dips are from 80° W. to 80° E. Fracture cleavage is prominent throughout the mudstone and has an average strike of about N. 25° E. and an average dip of 80° W. Two well defined and one poorly defined joint sets underlie the test site and dip at 20° (the most prominent), 45°, and 70° (the least prominent).

Although the moisture content of the mudstone has not yet been determined at depth, moisture determinations conducted within 10 feet of the surface indicate that the moisture content of the rock ranges from 3.1 percent in the thawed mudstone to 12.5 percent in the frozen mudstone.

The use of refrigerated diesel fuel as drilling fluid in Holes Charlie and Dog in 1960 overcame the collapse of drill-hole walls owing to thawing of permafrost experienced in the drilling of Holes Able and Baker by conventional techniques in 1959.

Work on coastal processes was focused on establishing a physical background for ecological studies being conducted by other investigators and on characterizing the natural movement of sediment as an aid in evaluating the success and safety of the proposed nuclear test. The 1960 surf year began on July 5, when the pack ice left the shore, and it ended on October 21, when the beach became stabilized by the formation of a kaimoo (an ice rampart) on its surface. Disturbance by sea ice during the breakup period was seen to have almost no effect on the beach sediments. Under changing surf conditions, beach material moved both to the east and west along the shore, but at the end of the surf year, a net of nearly 30,000 cubic meters of sediment had moved toward the west.

Piston-core samples from lagoons which do not contain the mouths of rivers and streams show that only about 10 centimeters of sediment have been laid down in the lagoons since the last major rise of sea level. The inferred shoreline history of the area is as follows: between 100,000 and 63,000 years ago, sea level reached a point approximately 8 meters above its present stand; this period of high sea level was followed by 50,000 years during which the sea withdrew leaving a tundra-covered land area. Sea level rose again 5,000 years ago to a point about 3 meters below its present position; subsequently it rose slowly and irregularly, attaining its highest stand in the 19th century.

The two new holes (Charlie and Dog), drilled through permafrost, are providing much of the precise temperature information needed for a quantitative evaluation of the thermal regime of lower Ogotoruk Creek valley. The depth and temperature of permafrost are affected by the proximity of surface bodies of water, especially the sea, and of major irregularities in topographic relief. At a point 300 feet inland, the bottom of permafrost ($0^{\circ}C$ isotherm) is at a depth of 945 feet; 4,000 feet inland it is unaffected by the sea and extends to a depth of 1,170 feet.

The thermal regime of permafrost is not in equilibrium with the present position of the shoreline or the present climate. If the present climate persists it will result in thinning of the existing permafrost by raising the bottom about 300 feet. The thinning has not yet commenced, however, as the present climatic change has been in progress for only the past century. The total increase in mean ground surface temperature during this period has been on the order of $2^{\circ}C$. The change has not been uniform throughout the valley, and it is likely that the differences can be traced to microenvironmental factors which are also in the process of change.

Independent of the climatic effect, if the present shoreline were in thermal equilibrium with the earth, an additional 300 feet or so of permafrost would have been removed at points 300 feet inland. An encroachment of the sea in the past 2,000 to 5,000 years is indicated by preliminary calculations based on the assumption that the transgression occurred abruptly in a single stage. A more gradual transgression would have initiated at an earlier date. At present permafrost extends beneath the margin of the Chukchi Sea in the Chariot site area.

Preliminary calculations indicate that the flow of heat to the surface from the earth's interior is on the order of one millionth of a calorie per square centimeter of surface per second. This is close to the worldwide average, contrary to the speculation of some that the Arctic is anomalous in this respect.

A series of gravity measurements between Kotzebue and Point Hope indicate a broad uneven gravity low with double minimums near Cape Seppings and Kivalina. This low is probably caused by a thick accumulation of Mesozoic sediments and is similar to the gravity low associated with the Colville geosyncline south of Point Barrow. Near Cape Seppings the anomaly appears to have a magnitude of about 30 milligals, but some of this value may be caused by gravity gradients normal to the general trend of the coastline profile. Gravity gradients on both sides of the anomaly are gentle, and significant variations are not associated with the outcrops of faults mapped on the surface. However, there is little density contrast between the formations cropping out near Ogotoruk Creek, and large gravity gradients were not expected.

Shallow and deep aquifers exist in the Chariot test site area. The shallow aquifers, which consist principally of unconsolidated material, depend upon recharge during flood stages of the creeks and are drained during low water. The deep aquifers are in permeable portions of bedrock and receive recharge water from distant sources. Any radioactive fallout in the Ogotoruk Creek drainage could contaminate the shallow alluvial aquifer of the creek; however, it appears that the aquifer is essentially depleted and replenished each year. Water that is retained in the sand and gravel probably is flushed out the following year, except possibly for a wedge lying below sea level near the mouth of the lagoon. Whether this wedge is removed each year is not known, but it might become a point of accumulation of any radioactive material contaminating the shallow aquifer.

Substantial radioactive fallout inland probably would contaminate the deep aquifers. The aquifers could be contaminated by recharge from snowmelt or rain water percolating into the rocks. Radioactivity could be concentrated in some recharge areas by drifting snow accumulating in sheltered areas if the detonations are conducted during winter or spring months. It is unknown whether dilution or adsorption in the aquifers and streams would reduce the radioactivity to safe limits if initially high concentrations of radioactivity should occur.

For all practical purposes, no flow occurred in Ogotoruk Creek from late October 1959 to mid-May 1960. Some flow may have occurred on scattered days during this period but amounts were too small to be of importance in the overall surface-water study. The surface flow of Ogotoruk Creek during the summer months of the 1960 water year was substantially less than that of the 1959 water year.

General Introduction

In 1958 the U. S. Atomic Energy Commission requested the U. S. Geological Survey to conduct geologic studies that would contribute to a determination of the feasibility and safety of creating a harborlike excavation by detonation of several nuclear devices along the northwest coast of Alaska. Known as Project Chariot, the proposed test, located on Ogotoruk Creek, is one phase of the Atomic Energy Commission's Plowshare Program to develop peaceful uses of atomic energy.

Although this preliminary report covers chiefly geologic work done during the 1960 field season, it also amplifies and updates information obtained in field and laboratory investigations during 1958 and 1959. The present report includes all phases of the Geological Survey's program outlined in the May 1960 Work Plan and Operating Budget for Chariot

Phase III. It also includes a chapter on site geology and a chapter on a gravity survey. All the pertinent problems associated with the Geological Survey's Chariot Phase III investigations are considered in this preliminary report. Some revisions and additions of significant findings may be necessary when complete laboratory results have been obtained. The authors believe, however, that these revisions and additions will be slight and will not materially affect the conclusions expressed in this report.

Previous Work

In the spring of 1958, the U. S. Geological Survey, at the request of the Atomic Energy Commission, undertook a study to evaluate geologic and oceanographic factors pertinent to the selection of a site between Nome and Point Barrow, Alaska. The results of the study suggested three geologically feasible sites for the proposed nuclear test in a 20-mile coastal strip from Cape Seppings to Ogotoruk Creek (Péwé, Hopkins, and Lachenbruch, 1959). A field study of the three sites was recommended in the report.

Accordingly, a Survey field party spent from early July to late August 1958 making geologic and oceanographic studies of the three sites. These investigations demonstrated that the Ogotoruk Creek site was geologically best suited for the test nuclear excavation (Kachadoorian, and others, 1958; and Scholl and Sainsbury, 1959).

In 1959 the Survey was requested to continue its investigation directed toward determining the geologic environment of the proposed site. The scope of its investigations under this Chariot Phase II Program was expanded from that in 1958 and consisted of: (1) site geologic investigations, (2) areal geologic mapping, (3) coastal processes investigations, (4) geothermal investigations, (5) seismic velocity investigations that included in-hole velocity and seismic refraction studies, and (6) water resources investigations consisting of surface water, ground water, and quality of water studies. The results of the Chariot Phase II 1959 investigation are contained in two reports (Kachadoorian and others, 1960a; Kachadoorian and others, 1960b).

Present Work

The studies upon which this report is chiefly based were undertaken in support of the Chariot Phase III Program and, for the most part, constituted a continuation or expansion of field work initiated in 1959 and were as follows: (1) areal geologic mapping, (2) coastal processes investigations, (3) geothermal investigations, and (4) surface water and ground water investigations. Quality of water and seismic studies were not carried out during the 1960 field season. Lithologic logs of Holes Charlie and Dog that were drilled by Snow, Ice, and Permafrost Research Establishment of Corps of Engineers in 1960 were compiled in support of the geothermal and areal geologic mapping programs. Also, in support of the areal mapping program, a gravity survey was conducted at no expense to the Atomic Energy Commission.

Acknowledgments

The Geological Survey's field work was facilitated by the cooperation of the personnel of the Atomic Energy Commission; Wein Alaska Airlines; Holmes and Narver, Inc.; and Snow, Ice, and Permafrost Research Establishment of the U. S. Corps of Engineers. We particularly wish to acknowledge the cooperation of Henry Slacks and Meryle Smith of the Atomic Energy Commission; Ralph Chase, Harry Spencer, and William Lyons of Holmes and Narver, Inc.; and Jack Tedrow, William Harrington, and Robert Lange of Snow, Ice, and Permafrost Research Establishment.

Location

The Chariot test site lies approximately 110 miles north of the Arctic Circle along the northwest coast of Alaska at long 165°45' W. and lat 68°06' N. (fig. 1). The area is at the mouth of Ogotoruk Creek located about 125 miles northwest of the town of Kotzebue and 6-1/2 miles southeast of Cape Thompson. The village of Point Hope is 32 miles northwest of the test site.

Accessibility

The only means of access to the Chariot test site on Ogotoruk Creek is by boat, light aircraft, or tracked vehicle. Light single-engine aircraft can land at the site on (1) a 700-foot northwest-southeast airstrip built by U. S. Geological Survey personnel at the campsite in 1958, (2) a 400-foot north-south airstrip built in 1960 at the campsite by Holmes and Narver, Inc., and (3) a north-south airstrip approximately 1,000 feet long built in 1959 by Holmes and Narver, Inc., about three-quarters of a mile east of camp. Twin-engine aircraft can land on a 2,200-foot northwest-southeast airstrip built in 1959 by Holmes and Narver, Inc., about half a mile east of camp.

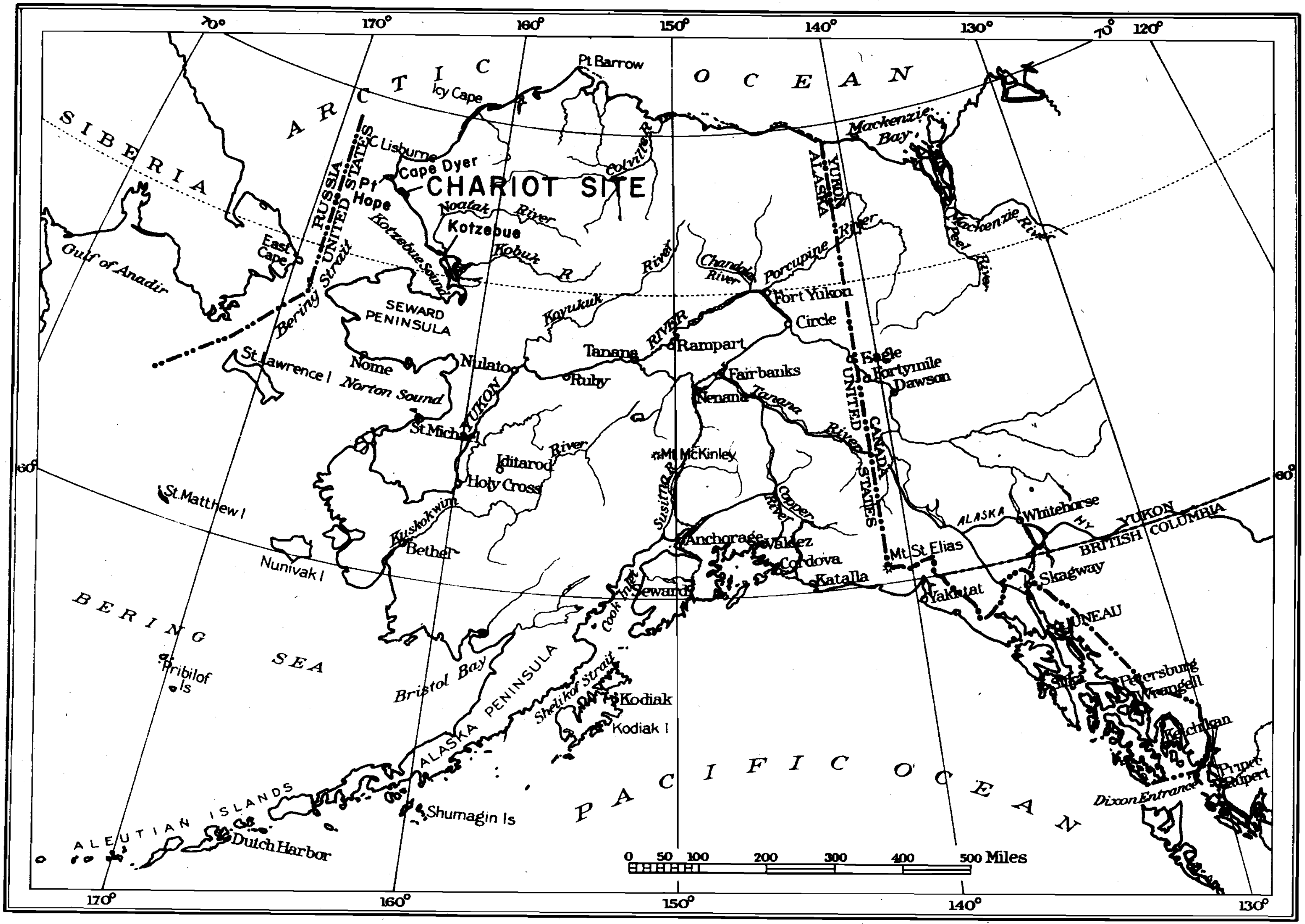

Figure 1.--Index map showing location of Chariot site, northwestern Alaska

Methods of field work

Field work by Geological Survey personnel consisted of a series of tracked-vehicle, foot, and boat traverses during which geological data were collected and plotted on vertical aerial photographs and later transferred to topographic maps. In addition, light aircraft on wheels and skis were used to get into the more remote and inaccessible areas.

The Survey personnel included two 2-man parties and one man working alone. One 2-man team started field work at the mouth of the Kukpuk River (fig. 3) in the first week of May. This party, doing a coastal processes study, later concentrated its attention on the Chariot test site. The second 2-man party started its study during the third week of June generally mapping within a semi-circular area that extends 15 miles from the Chariot test site; the party concentrated its efforts in the eastern and northwestern parts of the semicircular area. Other parts of the area were mapped in 1958 and 1959.

One man started field work in the last week of June and located the sites for Holes Charlie and Dog, collected surf data, made lithologic logs of the core from Holes Charlie and Dog, and collected general geologic data in support of all phases of the Geological Survey's program.

In addition to the above, Survey personnel doing the ground water, surface water, gravity, and geothermal investigations were also at the site from time to time.

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ENGINEERING GEOLOGY OF THE CHARIOT TEST SITE ON OGOTORUK CREEK NEAR CAPE THOMPSON, NORTHWESTERN ALASKA

by

Reuben Kachadoorian

Introduction

During the 1960 field season the author carried out detailed geologic investigations at Ogotoruk Creek site in support of all phases of the Geological Survey's Chariot Phase III program. In addition, he located and logged cores from Holes Charlie and Dog, provided geologic advice and counsel to other participants of the Chariot program, and provided a coordination and liaison function with other participants in the program.

Four diamond-drill holes now have been drilled at the Chariot test site (fig. 2). Holes Able and Baker, drilled in 1959, are 598 feet and 1,172 feet deep, respectively. Holes Charlie and Dog, drilled in 1960, are 1,002.1 feet and 1,202.2 feet deep, respectively. Holes Able and Baker were drilled by conventional techniques, whereas Holes Charlie and Dog were drilled with refrigerated diesel fuel. Lithologic logs of Holes Able and Baker are included as tables 5 and 6 in the Survey's preliminary report for Chariot Phase II (Kachadoorian and others, 1960a); tables 1 and 2 of this report are detailed logs of Holes Charlie and Dog.

To prevent the frozen core from Holes Charlie and Dog from thawing, diesel fuel was chilled to an average temperature of 18° F and used as drilling fluid. The frozen core was tentatively logged in the field, placed in a home freezer, and shipped to the SIPRE cold-room

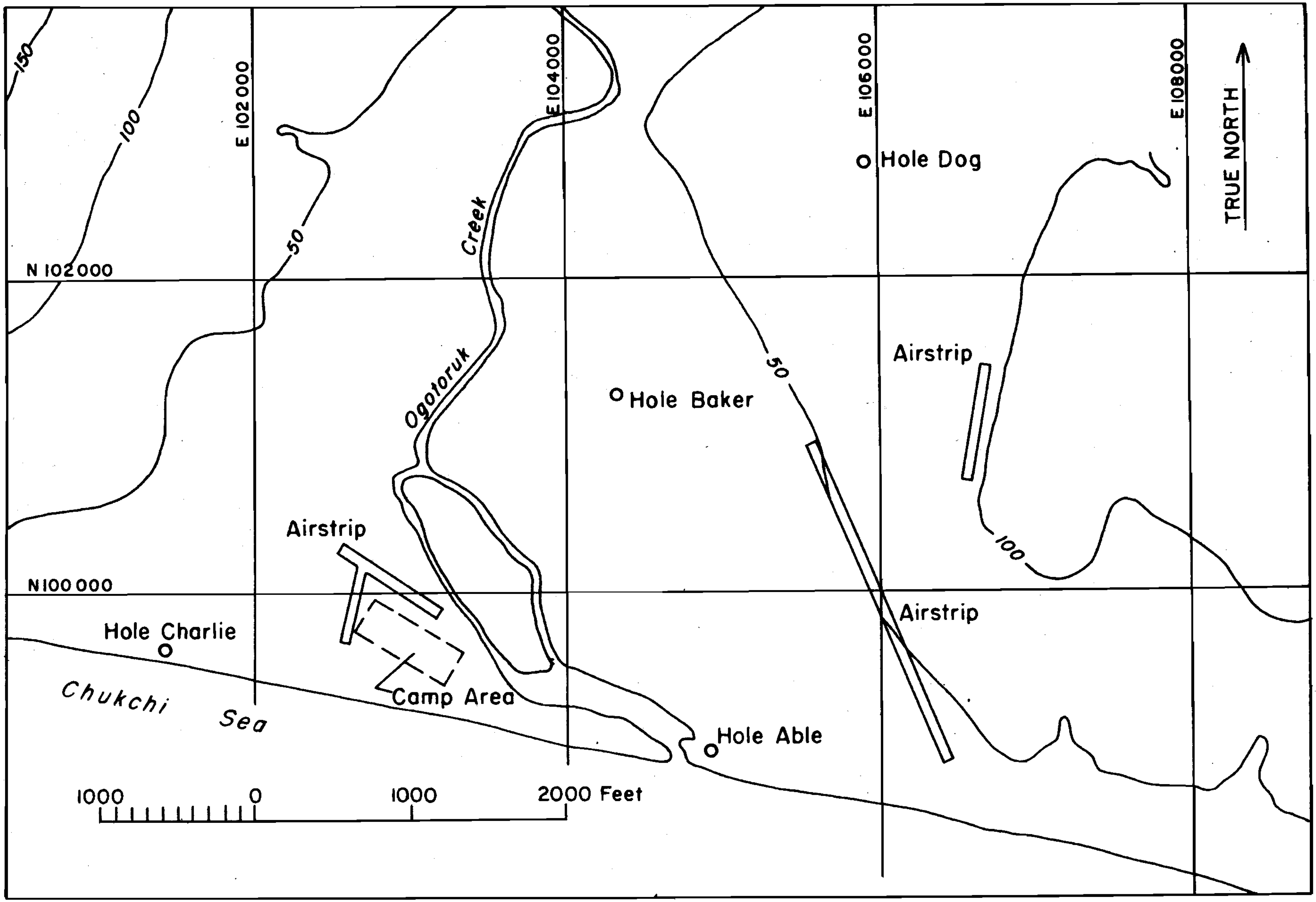

Figure 2.--Index map showing locations of Holes Able, Baker, Charlie, and Dog, Chariot test site, northwestern Alaska

laboratory in Wilmette, Illinois, where it was logged in detail by the author. Core was not obtained below the bottom interface of permafrost approximately 945 feet deep in Hole Charlie and 1,170 feet deep in Hole Dog.

Continuous coring of the holes was neither planned nor attempted, but was done at 100-foot intervals agreed upon by SIPRE and the USGS. This decision was based on the knowledge of the lithology of the Chariot site area obtained during the drilling of Holes Able and Baker in 1959. Occasionally a slight variation from the 100-foot interval was necessary due to slight changes in lithology. The amount of core obtained was about 88 feet from Hole Charlie and about 100 feet from Hole Dog.

Geology

Bedrock

The site is located entirely in complexly folded and faulted mudstone of the Tiglukpuk(?) formation of Jurassic age. Locally, the mudstone is exposed on the surface as splinters 1/8 to 1/4 inch thick, 1/2 to 1 inch wide, and about 3 inches long. At depth, however, the mudstone is not splintered but instead is relatively sound due to healing of the fractures by ice. Also at depth, the mudstone in part is more massive (tables 1 and 2).

Kachadoorian (1960a) believed that the moisture content was higher than reported by the Anchorage, Alaska laboratories of the Corps of Engineers. They reported a moisture content of thawed samples of mudstone to range from 0.28 to 5.67 percent (written communication, 1959). The Corps of Engineers were unable to consider the ice in

Table 1.--Lithologic log of Hole Charlie, Chariot site, northwestern Alaska

Depth (feet)	Description
0.0 - 1.5	Beach gravel, unfrozen
1.5 - 5.0	Frozen beach gravel with ice; ice lenses from 4.0 to 5.0 feet; gravel subrounded to rounded; pebbles to 1/2 inch in diameter, average size 1/4 inch. Top of permafrost at 1.5 feet.
5.0 - 9.1	Unable to core; frozen beach gravel; although frozen from 5.0 to 6.0 feet, ice content low; loss of drilling fluid from 5.0 to 6.0 feet; from 6.0 to 9.1 feet frozen gravel consisting of 50 percent ice and 50 percent subrounded to rounded pebbles to 2 inches in diameter.
9.1 - 13.2	Beach gravel, frozen, containing up to 20 percent ice; core in two pieces and fragments from 1 to 6 inches; gravel consists of subrounded to rounded pebbles to 1/2 inch in diameter, average is 1/4 inch in diameter; from 9.1 to 9.4 feet is clear ice lense.
13.2 - 21.4	Beach gravel, not cored; frozen, cuttings show high ice content. Bedrock at 21.4 feet.
21.4 - 22.9	Mudstone, frozen; not cored.
22.9 - 27.4	Mudstone, medium dark-gray, frozen, two pieces 5 inches long and fragments 1/4 inch thick; large pieces contain quartz veins; fault zone from 25.2 to 27.4 feet; fault contact at 25.2 feet, dips 85°.
27.4 - 107.0	Mudstone, frozen, not cored; cuttings indicate high quartz content from 40.0 to 67.0 feet.
107.0 - 115.0	Mudstone, dark gray, frozen, generally massive; breccia from 107.0 to 112.6 feet; brecciated fragments healed by ice; core massive from 112.6 to 115.0 feet; contains quartz vugs and veins to 1/8 inch thick. Bedding dips 60°.
115.0 - 194.9	Mudstone, frozen, not cored.

Table 1.--Lithologic log of Hole Charlie, Chariot site, northwestern Alaska--Continued

Depth (feet)	Description
194.9 - 203.6	Mudstone, dark-gray, frozen; core appears to be sound but is mostly breccia healed by ice, smallest fragments from 200.3 to 203.6 feet; quartz veins from 194.9 to 195.2 feet; 1/4-inch quartz veins at 199.0 feet; 1/4 inch ice healing fractures at 195.7, 197.3, and 198.0 feet.
203.6 - 295.7	Mudstone, frozen, not cored.
295.7 - 303.9	Mudstone, medium dark-gray, frozen; massive except from 295.7 to 296.8 feet, where thin-bedded; fragments due to drilling from 302.0 to 303.9 feet; thin quartz veins at 297.6 feet and in zone 299.6 to 299.8 feet; fracture cleavage healed by ice dips 80°; joint healed by ice dips 60°.
303.9 - 407.8	Mudstone, frozen, not cored; drilling very slow from 342.0 to 370.0 feet, where cuttings contain high quartz content and mudstone, medium-gray.
407.8 - 416.4	Mudstone, medium-gray, frozen; core in fragments 407.8 to 410.2 feet, massive from 407.8 to 416.4 feet; massive core contains quartz veins to 1/4 inch thick; hairline fractures healed by ice; joints dip 20°, healed by ice, and fracture cleavage dips 80°; bedding 80° to 85°.
416.4 - 507.8	Mudstone, frozen, not cored; drilled hard material from 440.0 to 476.0 feet, probably medium dark-gray mudstone with high quartz content.
507.8 - 516.8	Mudstone, medium-gray, frozen; massive except from 510.0 to 513.9 feet where originally highly fractured into 1-inch pieces now healed by ice; bedding from 1/4 to 3/4 inch thick, average 3/8 inch thick; tight joints, closely spaced, dip 75°.
516.8 - 607.8	Mudstone, frozen, no core.
607.8 - 619.0	Mudstone, dark-gray, frozen, massive; fracture cleavage dips 85°; bedding dips 80°; tight joints, widely spaced, dip 20°; fractures and joints healed by ice; quartz veins from 610.9 to 614.9 feet, 616.1 to 616.5 feet, and 617.3 to 618.3 feet; locally quartz veins to 1/4 inch thick.

Table 1.--Lithologic log of Hole Charlie, Chariot site, northwestern Alaska--Continued

Depth (feet)	Description
619.0 - 707.8	Mudstone, frozen, no core.
707.8 - 715.8	Mudstone, dark-gray, frozen; generally massive, however fragments from 713.4 to 715.8 feet; thin-bedded mudstone faulted against massive mudstone from 711.4 to 715.8 feet; thin beds less than 1/2 inch thick dip 88° to 90°; fracture cleavage dips 85°, healed by ice; joints 75°, generally tight, healed by ice, sand, and clay; joints noted only at 711.2 and 711.6 feet; quartz veins less than 1/16 inch thick at 711.5 and 712.1 feet.
715.8 - 803.2	Mudstone, frozen, no core.
803.2 - 807.4	Mudstone, dark-gray, frozen; massive from 803.2 to 805.4 feet; from 805.4 to 807.4 feet half of core massive, half thinly bedded; bedding in massive core dips 70°; thin fractures healed by quartz; quartz veins scattered throughout core.
807.4 - 815.0	Mudstone, frozen, no core.
815.0 - 817.7	Mudstone, dark-gray, frozen; core in fragments, largest piece 5 inches long; vertical fracture cleavage and tight joints dipping 60° noted in 5-inch pieces; core crumbles easily; highly fractured due to drilling from 815.0 to 815.9 feet and 817.0 to 817.7 feet.
817.7 - 887.8	Mudstone, frozen, no core.
887.8 - 889.7	Mudstone, dark-gray, frozen; fractured along bedding planes into tabular pieces generally 1 by 2 by 3 inches; quartz veins and veins less than 1/16 inch thick from 889.5 to 889.7 feet; bedding vertical.
889.7 - 1002.1	Mudstone; estimated depth of permafrost 945 feet; unable to core; mudstone dark-gray and soft. Bottom of hole at 1002.1 feet.

Table 2.--Lithologic log of Hole Dog, Chariot site, northwestern Alaska

Depth (feet)	Description
0.0 - 1.2	Vegetation material and windblown sand and silt; no core.
1.2 - 1.8	100 percent ice; top of permafrost 1.2 feet.
1.8 - 2.0	Colluvium, frozen, 95 percent ice with 5 percent randomly oriented fragments to 1 inch long.
2.0 - 2.6	Colluvium, frozen, 50 percent ice and 50 percent randomly oriented fragments to 1 inch long; 1-inch ice lens at 2.5 feet.
2.6 - 3.3	Colluvium, frozen, 50 percent ice and 50 percent bedrock fragments to 1 inch long with slight vertical orientation.
3.3 - 8.5	Colluvium grading into mudstone bedrock; frozen, ice content 50 percent at 3.3 feet decreases to 10 percent at 8.0 feet; stratification of tabular mudstone fragments becomes progressively more uniform and vertical at depth and fragments become progressively larger; at 3.3 feet fragments average 1/2 inch long, at 8.5 feet average is 3 inches long; ice lenses from 4.8 to 4.9 feet, 5.6 to 5.7 feet, and 8.0 to 8.4 feet; ice content increases from 8.0 to 8.5 feet. Bedrock at 8.5 feet.
8.5 - 10.4	Mudstone, frozen; highly fractured from 8.5 to 9.2 feet with estimated 20 percent ice; 9.2 to 10.4 feet mudstone, more sound; bedding dips 85°; ice between bedding planes.
10.4 - 94.9	Mudstone, frozen, no core.
94.9 - 102.2	Mudstone, medium dark-gray; frozen; massive except from 95.7 to 97.0 feet, which is zone of healed breccia; vertical fracture cleavage healed by ice; bedding appears to dip from 70° to 80°; tight joints healed by ice, dip 20°, located at 95.8, 100.2, and 101.8 feet.
102.2 - 194.5	Mudstone, frozen, no core.
194.5 - 200.2	Mudstone, medium dark-gray, frozen; core highly fractured from 194.5 to 198.0 feet; relatively massive from 198.0 to 200.2 feet; fractures healed by ice; fault gouge from 197.1 to 197.4 feet; dips 60°; quartz veins and vugs from 194.9 to 195.1 feet; fractures dip 70° and 10° to 15°; joint dips 20° at 194.9 feet.

Table 2.--Lithologic log of Hole Dog, Chariot site,

northwestern Alaska--Continued

Depth (feet)	Description
200.2 - 291.0	Mudstone, frozen, no core.
291.0 - 302.0	Mudstone, dark-gray, frozen; generally massive, highly fractured from 299.2 to 299.9 feet, and crumbles easily at 301.2 feet; fractures healed by ice or quartz; quartz veins less than 1/64 inch thick from 298.8 to 299.0 feet and 300.0 to 300.2 feet; joints: one set dips 20° at 291.9, 294.2, 299.2, and 299.8 feet; another set dips 45° at 296.7 and 298.8 feet.
302.0 - 407.2	Mudstone, frozen, no core.
407.2 - 413.5	Mudstone; medium-gray, massive from 407.2 to 410.7 feet; dark-gray, thin-bedded, friable and soft from 410.7 to 413.5 feet; frozen; fault zone from 410.7 to 413.5 feet; fracture cleavage dips 60° and joint dips 45°, both healed by ice; small quartz veins less than 1/64 inch thick throughout core.
413.5 - 495.0	Mudstone, frozen, no core.
495.0 - 505.3	Mudstone, dark-gray, frozen; massive except from 498.2 to 499.5 feet, where highly fractured, some due to drilling; fracture cleavage dips 80° from 495.0 to 500.3 feet; fractures all healed by ice and quartz from 495.0 to 498.4 feet; from 498.4 to 500.3 feet some fractures open, others healed by quartz; bedding dips from 75° to 80°; quartz stringers less than 1/32 inch thick throughout core.
505.3 - 596.4	Mudstone, frozen, no core; cuttings indicate local quartz veins.
596.4 - 607.6	Mudstone, medium dark-gray, frozen; massive and highly fractured; fracture zones from 602.3 to 603.0 feet, 604.0 to 604.2 feet, and 605.0 to 605.1 feet; fault breccia from 596.4 to 597.4 feet; fractures healed by ice from 602.9 to 604.7 feet and 605.7 to 606.4 feet; quartz veins throughout core, which locally heals joints dipping 20° and fracture cleavage dipping 85°.
607.6 - 694.6	Mudstone, frozen, no core.

Table 2.--Lithologic log of Hole Dog, Chariot site, northwestern Alaska--Continued

Depth (feet)	Description
694.6 - 704.1	Mudstone, dark-gray, frozen; generally massive except fragments due to drilling from 701.0 to 701.5 feet and at 703.0, 703.5, and 703.9 feet; fracture cleavage dips 80°; some healed by ice; joint dips 25° at 699.0 feet.
704.1 - 796.6	Mudstone, frozen, no core.
796.6 - 806.4	Mudstone, dark-gray, frozen, massive; quartz throughout core as thin stringers especially from 796.6 to 798.2 feet, 800.7 to 802.1 feet, and 802.9 to 805.0 feet; talcosic vugs to 1/2 inch thick from 800.7 to 802.1 feet and at 804.2 feet; fracture cleavage dips 85° and healed by ice; joints dip 20° at 798.0 and 801.8 feet, also healed by ice; ice crystals noted in fresh fracture.
806.4 - 894.9	Mudstone, frozen, no core.
894.9 - 901.8	Mudstone, dark-gray, frozen, massive but fractured due to drilling from 899.2 to 900.3 feet and at 901.2 feet; bedding appears to dip 80°; abundant quartz veins and vugs throughout core; joints, dip 45°, loose, and spaced 0.1 to 1.2 feet apart; joints may be loose due to drilling.
901.8 - 994.9	Mudstone, frozen, no core.
994.9 - 1005.0	Mudstone, medium-gray, frozen, massive; bedding dips 80°; throughout core quartz veins have healed hairline fractures; quartz vugs to 1/4 inch thick at 1001.4 feet and from 1002.4 to 1005.0 feet; one set of tight joints dips 45° at 996.5, 997.6, and 998.0 feet; one joint set dips 20° at 1003.4 feet; joints generally healed by quartz.
1005.0 - 1100.0	Mudstone, frozen, no core.
1100.0 - 1103.4	Mudstone, medium-gray, frozen, although ice not noted; massive; bedding dips 45°; quartz stringers less than 1/32 inch thick from 1101.4 to 1102.5 feet; joints dip 20° and 45°, tight and widely spaced.
1103.4 - 1202.2	Mudstone, no core; estimated bottom of permafrost at 1170 feet. Cuttings indicate mudstone generally massive with local zones of thin-bedded material; some massive zones contain quartz veins of unknown thickness, location, and amount.

fractures and in joints because the core furnished them for moisture determinations was thawed. The Survey has not yet determined moisture content on the frozen core obtained from Holes Charlie and Dog. They have, however, determined moisture contents of samples of mudstone, obtained within 10 feet of the surface, during the high explosive test conducted at the Chariot site during November 1960. The results show that the moisture content ranged from 3.1 percent in the thawed mudstone to 12.5 percent in the frozen mudstone. Locally, ice wedges 6 inches thick were observed in the 9.6-foot high-explosive test hole. It should be pointed out that these results were obtained in a test hole only 9.6 feet deep and may not reflect the moisture content of the mudstone at depth.

Structure

The rocks that underlie the Chariot test site are tightly folded, locally overturned, mudstone. Thus, the dip of the beds ranges from horizontal through vertical. However, although the beds are tightly folded, the average dip is about 80°. The strike of the beds varies also, but is far more uniform than the dip and averages about N. 20° E.

Fault zones are numerous in the core from Holes Charlie and Dog. At least four zones were observed in the 88 feet of core from Hole Charlie and four from the 100 feet of core from Hole Dog (tables 1 and 2). In comparison, six fault zones were noted in 598 feet of core from Hole Able and 26 zones noted from about 858 feet of core from Hole Baker (Kachadoorian and others, 1960a). The fault zones in Hole Charlie ranged from 2.2 to 8.0 feet thick; in Hole Dog they ranged from 0.3 to 2.8 feet thick. In Holes Able and Baker most of the fault zones were less than one foot thick. In Hole Baker a 14.3-foot zone, the largest noted in any of the four holes, exists between depths of 239.7 to 254.0 feet. The displacement along the fault zones could not be determined.

The attitude of the fracture cleavage is fairly uniform. The average strike is N. 25° E. and the dip varies from 60° E. to 75° W. The most common dip, by far, is 80° E. Locally, when the fracture cleavage is along the bedding of the mudstone, a question arises whether the parting is fracture cleavage or is due to unloading during the coring process. In the permafrost zone, most of the fracture cleavage partings have been healed by ice or quartz veins.

There are at least two, possibly three, sets of conjugate joints: one dipping 20°, a second dipping 45°, and possibly a third dipping 70°. The most prominent set dips 20°. The spacing of this set varies from 0.1 foot to 5 feet. The 45° set is not as common as the 20° set and joints were observed as being spaced 0.1 foot to 2.1 feet apart. The 70° joint set is the least common and is noted only occasionally at depths below 500 feet in Hole Charlie. Most of the joints are tight and commonly healed by quartz or ice that occurs in the permafrost zone.

For a more detailed description of the geology of the Chariot test site the reader is referred to previous reports by the Geological Survey in support of the Chariot program (Kachadoorian and others, 1958 and 1960a).

Unconsolidated deposits

Unconsolidated deposits of Quaternary age overlie the mudstone and consist of beach deposits, terrace deposits, silt and sand, colluvium, alluvial fan deposits, swamp deposits, flood plain deposits, and modern beach deposits. In the site area these deposits are generally less than 12 feet thick but locally may be as much as 30 feet thick.

For a more detailed description of the unconsolidated deposits, the reader is referred to an earlier Survey report (Kachadoorian and others, 1958).

Permafrost

Permafrost, or perennially frozen ground, underlies the Chariot test site. The depth to permafrost in areas of bedrock was observed to be 4 feet adjacent to the north-south airstrip east of Ogotoruk Creek; elsewhere the depth is unknown but is believed to be less than 10 feet. In unconsolidated deposits, except modern beach deposits and flood plain deposits, permafrost generally lies 1 foot to 3 feet below the surface. The top of the permafrost is unknown in modern beach deposits but believed to be less than 25 feet deep. Permafrost lies within 5 or 6 feet of the surface in the flood plain deposits. Permafrost was encountered 2.4 feet below the surface in Hole Able; 2.1 feet in Hole Baker; 1.5 feet in Hole Charlie; and 1.2 feet below the surface in Hole Dog.

Ice wedge polygons are common in the Chariot site area and are confined to areas of sand and silt deposits (Kachadoorian and others, 1958, pls. 1 and 3). Frost boils are also numerous throughout the

Chariot site area. They are not, however, confined to areas of silt and sand, although they are best developed in silt and sand and colluvium deposits.

During the drilling of Holes Able and Baker by conventional techniques, serious difficulties arose owing to thawing and collapse of hole walls. To overcome this difficulty, refrigerated diesel fuel was used as the drilling fluid during the drilling of Holes Charlie and Dog in 1960. This technique, developed by SIPRE, worked as expected and resulted in two absolutely clean holes. No problems were encountered during the insertion of the thermistor cables, although three cables were placed in Hole Charlie and two in Hole Dog. A detailed discussion of the results obtained from the thermistor cables in Holes Able, Baker, Charlie, and Dog is presented later in this report by Lachenbruch, Greene, and Marshall.

Summary and conclusions

The Chariot test excavation lies entirely in frozen mudstone which has been complexly folded and faulted. Locally, the rocks are overturned. The mudstone contains numerous fault zones, most of which are less than 5 feet wide, with the exception of a 14.3-foot fault zone in Hole Baker and an 8-foot zone in Hole Charlie.

The strike of the mudstone averages N. 20° E. and the most common dips are from 80° W. to 80° E. Fracture cleavage striking N. 25° E. with an average dip of 80° E. is relatively uniform throughout the mudstone. Two well defined and one poorly defined joint sets underlie the test site. They occur at 20° (the most prominent), 45°, and 70° (the least prominent).

The moisture content of the mudstone has not been determined at depth. However, at depths within 10 feet of the surface the moisture content varies from 3.1 percent in thawed mudstone to 12.5 percent in frozen mudstone. Locally, ice wedges 6 inches thick occur.

The use of refrigerated diesel fuel as drilling fluid in drilling Holes Charlie and Dog in 1960 overcame the collapsing of drill hole walls due to thawing of permafrost encountered during the drilling of Holes Able and Baker in 1959. Holes Able and Baker were drilled with conventional techniques using conventional "mud" to maintain the integrity of walls of the holes.

The drilling or digging of the large device holes will present a major engineering problem. Extensive slumping of the walls experienced in 1959 during the drilling of Holes Able and Baker indicates that similar difficulties should be expected in the construction or drilling of the large device holes. The experience of drilling Holes Charlie and Dog shows that the difficulties can be overcome by using refrigerated diesel fuel if the large holes are drilled or by using cribbing or any other proper mining technique if the holes are mined.

References cited

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Kachadoorian, Reuben, and others, 1960a, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska--preliminary report: U. S. Geol. Survey TEI-753, 94 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

AREAL GEOLOGIC MAPPING IN THE CAPE THOMPSON AREA, ALASKA

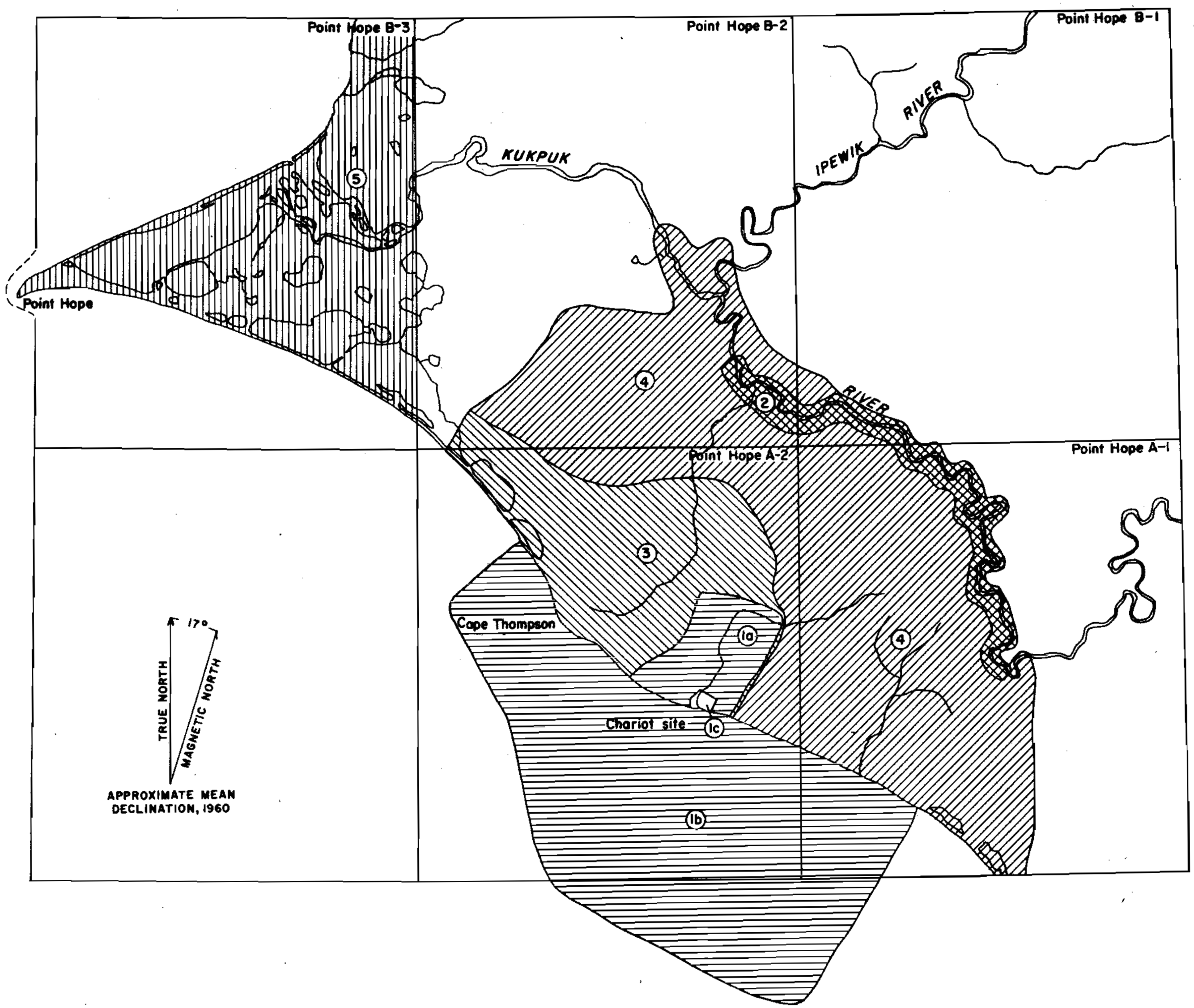
by

Russell H. Campbell

Introduction

The main objective of the areal mapping program is to provide a general-purpose geologic map and report on an area of about 350 square miles in the vicinity of the Chariot test site. The generalized geologic map included in this report (pl. 1) is a compilation at a scale of 1:125,000, which shows the distribution of the major bedrock units and their broad structural relationship. It serves primarily as an illustration of the regional structure from which interpretation may be made concerning the deformational history of the area. The more detailed and complete compilation of the geology of the area at 1:63,360 scale is in preparation and will be submitted with a comprehensive report on the bedrock and surficial geology.

The field work in connection with the present areal geologic mapping program has been completed. Approximately 200 square miles were mapped during the 1960 summer field season by the writer assisted by D. R. Currey. The field work was done by weasel and foot traverses. The mapping was done on vertical aerial photographs at scales of 1:41,000 and 1:46,000 and transferred to topographic base maps. This area is shown on the index map (fig. 3), which shows areas where Geological Survey personnel connected with Project Chariot have done field work that contributes to the objective of the areal mapping program. It does not include all areas



1. Kachadoorian, Reuben; Campbell, R. H.; Sainsbury, C. L.; and Scholl, D. W., 1958, Geology of the Ogotoruk Creek area, northwestern Alaska: U. S. Geol. Survey open-file report, TEM-976

   1a. Plate 1, Geologic map and sections of Ogotoruk Creek area, 1:12,000, by Reuben Kachadoorian, R. H. Campbell, C. L. Sainsbury, and D. W. Scholl

   1b. Plate 2, General bathymetry and marine geology of Ogotoruk Creek area, about 1:31,680, by D. W. Scholl and C. L. Sainsbury

   1c. Plate 3, Engineering geology map of part of Ogotoruk Creek area, 1:4,800, by Reuben Kachadoorian and R. H. Campbell

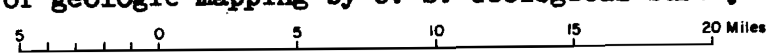
2. Sainsbury, C. L., and Campbell, R. H., 1959, Geologic strip map of part of the Kukpuk River, northwestern Alaska, U. S. Geol. Survey open-file report, about 1:42,000

3. Campbell, R. H., 1960, Preliminary geologic map and diagrammatic structure sections of part of the Point Hope A-2 quadrangle, northwestern Alaska, in Kachadoorian, Reuben, and others, 1960, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska, Preliminary Report: U. S. Geol. Survey TEI-753, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn., Plate 2, 1:48,000

4. Campbell, R. H., geologic mapping during summer, 1960

5. Moore, G. W., Geologic mapping during summer, 1960

Figure 3.--Index of geologic mapping by U. S. Geological Survey on behalf of Project Chariot



studied by all Geological Survey personnel on Project Chariot. For example, it excludes work done by the Coastal Processes party along the coast from Sheshalik to Point Hope and work done in the Covroeruk Springs area in connection with ground-water investigations. In addition to final map compilation, the work in progress consists of paleontologic and petrographic laboratory examination of specimens collected during the past three field seasons, synthesis of data bearing on the Tertiary and Pleistocene erosion history of the area, and preparation of a final comprehensive report.

Stratigraphy

The bedrock of the map area consists entirely of consolidated clastic and chemical sediments, probably all of which were deposited in marine environments. Mudstone, sandstone, limestone, dolomite, chert, and argillite are the most common rock types. The rocks exposed in the map area range in age from Early Mississippian to Cretaceous(?). The units crop out in north-trending bands progressing generally from older beds on the west to younger beds on the east, with local complications in the intensely thrust-faulted area (pl. 1). The bedrock is concealed in more than 50 percent of the area by a thin cover of unconsolidated sediments and vegetation. The unconsolidated deposits consist of peat, sand, silt, and gravel, and occur as wind-deposited silt and fine sand, colluvium (the most abundant of the unconsolidated deposits, largely a product of mass wasting), lake and swamp deposits, flood plain deposits, beach gravel deposits of two or three different ages, and terrace gravel deposits at several levels along the course of the Kukpuk River, Ogotoruk Creek, and minor streams. The unconsolidated deposits are generally less than 20 feet thick but in a few places are much as 60 feet thick. Most of them are probably of Quaternary age but some may be of Tertiary age.

Devonian(?) rocks

The oldest rocks known in this part of northwestern Alaska are thickly bedded interbedded sandstone and mudstone of an unnamed unit of probable Devonian age. These rocks are exposed northwest of the mapped area along the lower reaches of the Kukpuk River and along the sea cliffs from north of Point Hope to Cape Dyer (figs. 1 and 3). Although they do not crop out within the mapped area, they underlie it at shallow depth as indicated on the structure section (pl. 1).

The sandstone is chiefly medium dark-gray very fine- to fine-grained feldspathic graywacke with variable amounts of calcite cement. The chief minerals are quartz, plagioclase, K-feldspar (microcline?), and muscovite. The mica, generally fine grained, occurs as coarse grains in some beds. Calcite cement is abundant in many beds but virtually absent in some. Rock fragments are commonly present, but not abundant. Minor amounts of carbonaceous(?) material and authigenic pyrite are disseminated in the rock. Preliminary X-ray examinations suggest that chlorite and illite predominate in the clay fraction. Cross-cutting veins of calcite or quartz or both are locally abundant.

The mudstone varies from medium light gray to black, apparently depending on the amount of contained carbonaceous material. Preliminary X-ray examinations suggest that the mudstones are chiefly illite, chlorite, and quartz in widely ranging proportions, generally with minor amounts of plagioclase.

The contact relationships of the Devonian(?) unit with the overlying unnamed unit of Mississippian age are unknown. The contact is obscured by surficial deposits in the areas visited by the writer and George W. Moore of the Geological Survey. Collier (1906, p. 18) reports that in two localities near Cape Dyer the contact is conformable. Collier (1906, p. 16-17) estimates a minimum of 1,000 feet and suggests as much as 2,000 feet for the thickness of the exposed strata, with an additional unknown thickness not exposed. The base of the Devonian(?) unit is not exposed in this part of Alaska.

Mississippian rocks

Three units of Mississippian age are shown on the accompanying geologic map (pl. 1). An unnamed mudstone-sandstone unit probably at least 2,000 feet thick is the oldest unit exposed within the mapped area. It is overlain by limestone and dolomite of the Lisburne group, of which two subdivisions are shown on plate 1. The three units appear to represent continuous marine deposition from Early to Late Mississippian time.

Sandstone-mudstone unit, unnamed.--The unnamed sandstone-mudstone unit of Early Mississippian age (Dutro, J. T., Jr., Sable, E. G., and Bowsher, A. L., written communication, 1958) has been described in a previous report (Campbell, 1960a, pl. 3) from exposures near the coast. During the summer of 1960, extensive exposures were found along several stream cuts in the northwestern part of the map area. The rocks in those outcrops are chiefly medium-gray to medium dark-gray silty mudstone, generally thin bedded and locally shaly, with a few zones of fossiliferous mudstone containing casts of brachiopods and crinoid columnals, as well as a few beds of silty limestone containing silicified horn corals and crinoid columnals. Rocks of the same unit exposed near the coast contain quartz sandstone interbeds and carbonized plant fragments which were not found in the inland stream cuts. This suggests that map unit Ms includes a much thicker section of marine mudstone than was seen in exposures along the coast in 1959.

Lisburne group.--Rocks of the Lisburne group of Mississippian age overlie the sandstone-mudstone unit conformably at a gradational contact. The Lisburne group is about 5,700 feet thick and consists chiefly of limestone and dolomite beds, in part cherty, with variable but minor amounts of interbedded black silty shale. The Lisburne has been described in previous reports (Campbell, 1960a, pl. 3, and Campbell, 1960b), in which five recognizable subdivisions were described. On the accompanying small scale geologic map (pl. 1), these have been grouped into two major subdivisions, lower and upper. In a few areas the two units occur together in complexly faulted relationships and are lumped together as undifferentiated Lisburne group rocks on plate 1.

The lower part of the Lisburne group consists predominantly of dark-gray bioclastic limestone with some interbedded shale. This unit includes units Ml_1, Ml_2, and Ml_3 of the previous reports. The lower Lisburne is about 2,000 feet thick and is overlain conformably by the upper Lisburne at a gradational contact.

The upper part of the Lisburne group is characterized by thick-bedded light-gray dolomite. This unit includes units Ml_4 and Ml_5 of earlier reports. It totals about 3,700 feet in thickness. The contact with the overlying Siksikpuk formation is obscured by faulting in areas where the rocks are well exposed; however, the relations appear conformable.

Permian and Triassic rocks

Greenish-gray argillite and chert, and black shale of the Siksikpuk formation of Permian age are overlain, apparently conformably, by black shale, gray and brown chert, and brown fossiliferous limestone of the Shublik formation of Triassic age. The Siksikpuk is about 400 feet thick and the Shublik is about 200 feet thick. The two thin units are locally folded and faulted, in places together with as much as a few hundred feet of beds of the lower part of the overlying mudstone-sandstone unit of Jurassic(?) and Cretaceous(?) age. The resulting map pattern is complex and these units have been grouped together on plate 1 to better illustrate their general distribution. The contact of the Shublik formation with the overlying mudstone-sandstone unit is apparently conformable, but nearly everywhere it is obscured by faulting and shearing of the basal mudstone of the overlying unit KJ_1.

Jurassic(?) and Cretaceous(?) rocks

Rocks of probable Jurassic and Early Cretaceous age include two lithologic units: a lower unit, KJ_1, in which mudstone predominates with minor amounts of interbedded sandstone; and an upper unit, KJ_2, in which sandstone and mudstone are interbedded in nearly equal amounts. Unit KJ_1 is estimated to be about 5,000 feet thick. In earlier reports this unit was tentatively assigned to the Tiglukpuk(?) formation (Kachadoorian and others, 1958), p. 19; Campbell, 1960a, pls. 2 and 3). Although it may be, in part, correlative with the Tiglukpuk formation (Patton, 1956) of the central Arctic Foothills physiographic province of northern Alaska, the lack of faunal evidence for the geologic age and the gradational character of its upper contact suggest that unit KJ_1, which does have local significance, is not entirely equivalent to the Tiglukpuk and should be given a local name. Unit KJ_2 is also estimated to be about 5,000 feet thick. It overlies unit KJ_1 with apparent conformity and the contact is probably gradational. The sandstone and mudstone beds of both units have similar lithologies and the subdivision is made on the basis of the relative abundance of interbedded sandstone. The sandstone is chiefly subfeldspathic lithic graywacke, and the mudstone has virtually the same composition as the silt and clay matrix material of the graywacke. No diagnostic fossils have been found in units KJ_1 and KJ_2 which have a total thickness of about 10,000 feet. Although the map distribution pattern does not indicate regional discordance and the lithologies are generally similar the contact relations with the overlying beds of Early Cretaceous age are obscured by complex folding and high-angle faulting.

Lower Cretaceous rocks

An unnamed unit, composed chiefly of massive to thinly laminated medium dark-gray to dark-gray mudstone overlies unit KJ_2. A zone containing relatively abundant interbedded graywacke is prominent at the base of the unit. At several localities fossils of Early Cretaceous age, including *Aucella crassicolis* (D. L. Jones, oral communication, 1960) were found in the mudstone and graywacke. The total thickness of the unit could not be accurately determined because of complex structure, absence of marker-horizons, and poor exposures; but at least 5,000 feet of strata are represented and possibly as much as 15,000 feet are present. Sandstone beds are rare except near the base, and the upper part of the unit contains only a few discontinuous zones in which thick sandstone beds occur. The contact relations with the overlying mudstone-sandstone unit are not certainly known.

Cretaceous(?) rocks

The youngest rocks exposed in the map area are those of the unnamed mudstone-sandstone unit in the eastern part of the map area. The unit is composed chiefly of thinly laminated to medium-bedded dark gray silty mudstone, commonly slightly micaceous, with variable amounts of interbedded thin- to thick-bedded feldspathic graywacke. The mudstone is brownish gray to medium dark gray and is commonly characterized by minute, discontinuous, uneven, internal laminae of dark-gray mudstone. The top of the unit is not exposed in the map area and the total thickness is not known but probably exceeds 1,000 feet. No fossils were found in these rocks, but the stratigraphic position indicates they are Early Cretaceous or younger in age.

Structure

The map area of plate 1 lies on the west flank of a structural trough, which is expressed by the map pattern of older rocks on the west and successively younger rocks on the east. This stratigraphic succession indicates that a greater thickness of sediments exists above the basement on the east than on the west side of the map area. This interpretation is consistent with gravity data obtained by R. V. Allen of the Geological Survey from traverses along and parallel to the coast line (see the chapter on gravity by Barnes and Allen, p. 80).

The geologic structure of the western half of the map area is dominated by north-trending imbricate thrust faults, on each of which the upper plate has been thrust eastward. In the eastern half of the area, the structures are predominantly northeast-trending folds and high-angle faults. The structures of both areas appear to be related to the same set of deforming stresses and were apparently formed contemporaneously. The difference between the structures of the two areas probably reflects the difference in response to the stresses by rocks of different competence rather than differences in time or orientation of the deforming stresses. The competent rocks of the Lisburne group broke along fault planes and moved eastward as thrust sheets. The less competent mudstone and sandstone of the Jurassic and Cretaceous units were instead intricately crumpled, and the strain was taken up by high-amplitude folding and many discontinuous small faults along bedding planes and axial planes of folds.

The structure section on plate 1 indicates a total net slip of slightly more than 5 miles to the east due to the thrust faulting. This is believed to be a minimum value, and the true displacement may well have been more than twice as great. Indirect evidence suggests a chronological order in which successively younger thrust sheets moved eastward over older thrust sheets. In places lobes of younger sheets completely overlap older sheets. The oldest thrust sheet is the plate above the Angmarok thrust fault. Following movement on the Angmarok thrust, part of at least one lobe of the Angmarok thrust sheet was dropped down along a high-angle fault. The next break occurred along the Saleekvik thrust fault, and its upper plate was thrust eastward over the Angmarok thrust plate. The Saleekvik thrust plate in turn was overridden in places by the Agate Rock thrust which was nearly contemporaneous with the overlying Eebrulikgorruk thrust fault. The Ahviknuk thrust fault appears to have been related to all of the previously mentioned faults, and renewed movement occurred along its plane during each of the thrust movements. High-angle faults cut the rocks of each thrust sheet and high-angle faulting was associated with each pulse of thrusting because many of the faults cut the rocks of lower plates but do not cut the overlying thrust planes.

The incompetent mudstone and sandstone of the Jurassic and Cretaceous section to the east of the thrust sheets were dragged beneath the basal thrust plane and strongly compressed as the thrust sheets of competent Lisburne rocks moved eastward. They yielded to this compression not by major thrust faults but by intense folding accompanied by displacement along hundreds of small discontinuous faults that followed bedding planes and axial planes of folds.

Basal rocks of unit KJ_1 are included in the upper plate above the Saleekvik thrust (included in areas labeled TRP for purposes of map and structure section (pl. 1). No regional discordance has been found between units KJ_1 and KJ_2 nor has any regional discordance been established between any of the younger Mesozoic sedimentary rocks within the map area. The major deformation, therefore, is probably younger than Early Cretaceous. In addition, the complex erosional history of the area suggests the deformation was no younger than middle Tertiary. It seems reasonable, therefore, to conclude that this deformation occurred in Late Cretaceous or early Tertiary time and was associated with the Laramide revolution.

The earliest Laramide deformation resulted in the development of a north- to northeast-trending syncline east of the map area, with an axis near Cape Seppings, and contemporaneous development of an associated highland to the west of the map area, possibly cresting in the vicinity of Point Hope. The western flank of the trough included the area of plate 1.

The faulting and folding of the sedimentary rocks may be interpreted as resulting from gravitational gliding of the thrust sheets down the east or northeast-dipping basement slope--the western limb of the syncline--along a major bedding plane fault at the base of the Lisburne group or in the upper part of the underlying Ms unit. The following structural history is reconstructed on the basis of the gravitational gliding hypothesis (de Sitter, 1954).

As the trough deepened, the east-dipping slope steepened to a critical angle and a bedding plane fault developed at the base of the Lisburne group, or within the incompetent mudstone just below the base of the Lisburne. This fault broke across the Lisburne beds along a north-trending, nearly flat plane near the present west flank of the valley of Ogotoruk Creek. The rocks above this fault--the Angmorak-Ahviknuk thrust fault--then moved eastward over the younger rocks until further movement was prevented by the resistance of the Mesozoic strata as they were folded and piled up in front of the Lisburne rocks. Concurrently, gentle folding took place in the upper plate, and drag tilted the beds below the fault vertically and locally overturned them. Jurassic(?) and Cretaceous rocks in the lower block tended to slide down the slope on top of the Lisburne rocks under the added load of the upper plate, causing high-angle faulting in the rocks below the upper plate. These faults broke through the upper plate and locally dropped the eastern extension of some lobes down on the east side.

When further movement on the Angmorak thrust was prevented, a new break occurred, the Saleekvik thrust, and the sheet of competent limestone (or most of it) was able to continue moving downslope along the Ahviknuk-Saleekvik fault plane until further movement was again arrested by the crumpled mass of strata piled up ahead of it. Continued downslope movement of upper plate rocks to the west, now buttressed by the immobilized upper plate rocks of the eastern front, resulted in gentle synclinal folding of the upper plate with an axis near the western side of the exposure of the upper plate of the Saleekvik thrust.

When the upper plate became immobile at the west flank of this syncline, a new break occurred, the Eebrulikgorruk thrust fault. Movement then took place along the Eebrulikgorruk-Ahviknuk thrust plane until the upper plate was again immobilized by a crumpled mass of incompetent strata at its front to the east. The Agate Rock thrust fault is apparently the lower boundary fault of a thick fault zone locally developed below the Eebrulikgorruk thrust fault.

The east-trending high-angle faults in the sheet above the Saleekvik fault were probably formed before that sheet was overridden by the Eebrulikgorruk thrust. The high-angle faults that cut the Ahviknuk thrust fault are probably associated with downslope movement of rocks of the western part of the upper plate of the Eebrulikgorruk-Ahviknuk thrust. The north-trending fault may represent a tendency to synclinal downbending caused by continued downslope movement of the western part of the upper plate as further easterly movement of the eastern part of the plate was resisted. Those that trend easterly are probably tear faults, and since they cut the north-trending fault, may have occurred after the upper plate rocks on the east were immobilized.

Subsequent erosion of the western highland and later subsidence below present sea level may have been associated with minor gentle folding of the thrust surfaces.

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COASTAL SEDIMENTATION IN NORTHWESTERN ALASKA

by

George W. Moore and David W. Scholl

Introduction

Work on coastal processes in connection with the Chariot Project in northwestern Alaska was focused on two principle objectives during 1960: (1) to establish a physical background for ecological studies being conducted in the Atomic Energy Commission program by other investigators; and (2) to characterize the natural movement of sediment as an aid in evaluating the success and safety of the proposed nuclear test in the area.

Field work was active from May 3 to September 3, 1960. Much of the work was directed toward defining conditions of coastal marine sedimentation in arctic environments. The physical characteristics of the environments were recorded both for the ice-free summer period and for the interval when sea ice dominates the landscape. New information was also obtained on past fluctuations of sea level, on the source and rate of transportation of beach material, and on chemical processes occurring within the sediments following their deposition.

Norbert W. Larsen assisted in the field work during the first part of the season and Reuben Kachadoorian participated in the work at many times during the course of the investigation. Don C. Foote, Atomic Energy Commission contractor, helped obtain simultaneous observations of surf characteristics over a broad area of northwestern Alaska; Donald L. Willson, U. S. Weather Bureau, measured wind velocities at an altitude of 1,000 meters; and Hans-Georg Bandi, Berne Historical Museum, arranged for dating of

samples by the radiocarbon method.

Sedimentary environments

Coastal sedimentation in northwestern Alaska occurs chiefly in three environments: on beaches, in lagoons behind barrier beaches, and in offshore areas. In addition, deposition of fluviatile sediments takes place within certain lagoons at the mouths of creeks and rivers.

Beaches

Ogotoruk Beach at the Chariot test site is a pebble-gravel beach consisting of very well sorted material. A composite sample was collected from a bulldozer cut about 2.5 meters deep across the beach. The modal diameter of the grains is 5.9 millimeters (fig. 4). The beach sediment is composed of 53 percent chert, 38 percent sandstone and mudstone, 7 percent limestone, and 2 percent vein quartz. These materials are derived from formations which crop out in nearby sea cliffs; exotic rock types are also present but only in amounts equal to a small fraction of a percent of the total grains. The poorly resistant sandstone and mudstone, derived from adjacent outcrops of rocks of Jurassic and Cretaceous age, undergo rapid attrition in the surf zone, and a few tens of kilometers away from their source areas they constitute only a minor part of the beach material. The other components are more resistant, but the significance of their relative abundance on different beaches in the area is partly obscured by sorting processes which systematically cause accumulation of certain materials on different parts of the beaches because of differences in specific gravity, shape, and grain size. Lithologic differences in beach-gravel

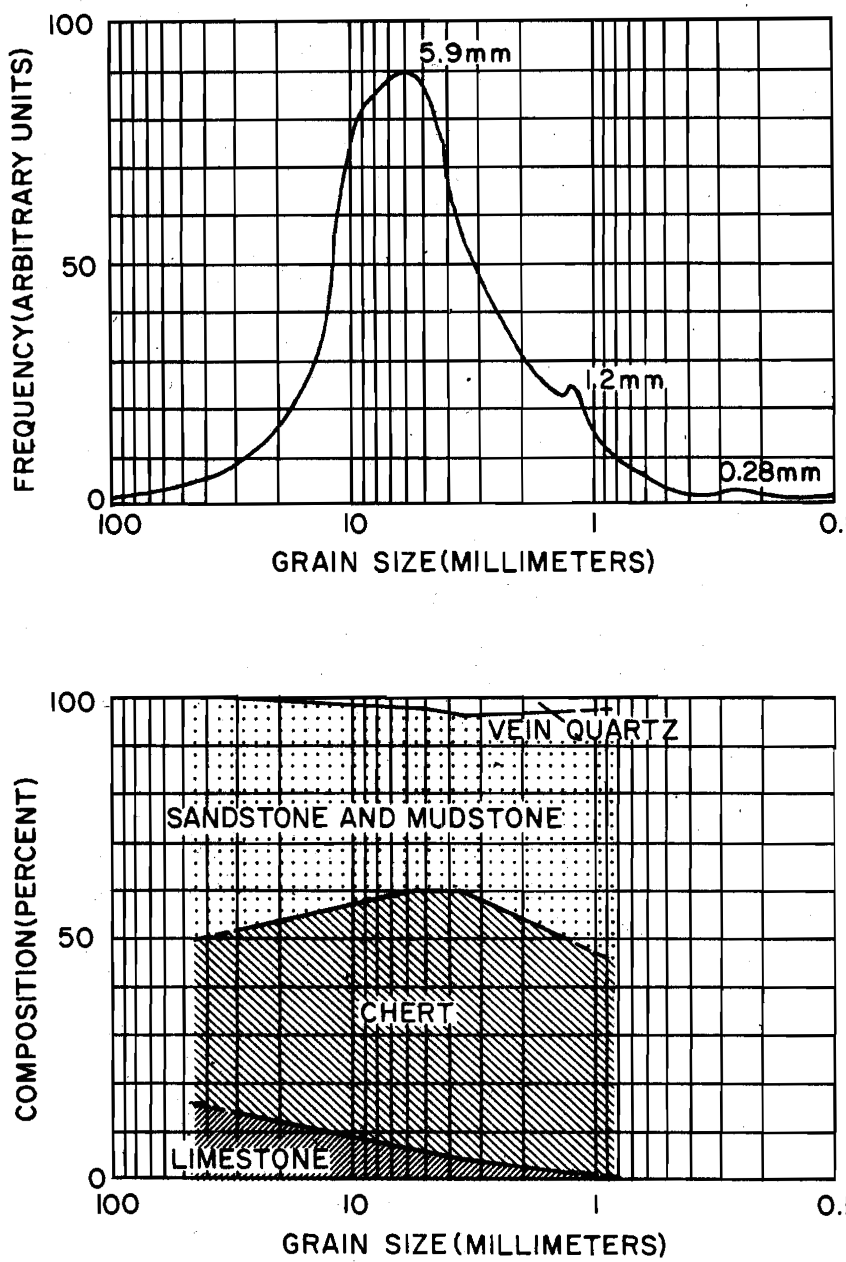

Figure 4.--Grain size and grain lithology of material on Ogotoruk Beach

samples taken consistently from the crest of the lowest berm along the coast from Point Hope to Cape Krusenstern suggest, however, that the relative percent of limestone is slowly reduced by attrition and solution during its alongshore transport (Moore and Cole, 1960). No limestone grains smaller than about a millimeter in diameter exist on the beach (fig. 4), and they probably have been destroyed by solution.

The material on the beaches, although already well sorted, is sorted still further by processes operating during any set of surf conditions. These processes cause the formation of prominent bedding which is expressed by thin sand layers interbedded with the gravel. A bulldozer cut made in May while the sea was still frozen illustrates the characteristic bedding of the beaches (fig. 5). The beds on the front face of the beach dip about 7° toward the sea, parallel with the face of the beach. Higher on the beach, the beds dip approximately 25° toward the land. These steep landward dips are formed when material is washed over the top of a berm during reconstruction following storm removal. On parts of the coastline where a barrier beach fronts a coastal lagoon, the landward dips are parallel to the slope that faces toward the lagoon.

Despite the coarse grain size of the sediment composing these beaches, little sea water is present in the interstices of the sediment. Water within the beach gravel is largely fresh, consisting of perched meteoric water augmented by a flux of fresh water which drains from the nearby tundra.

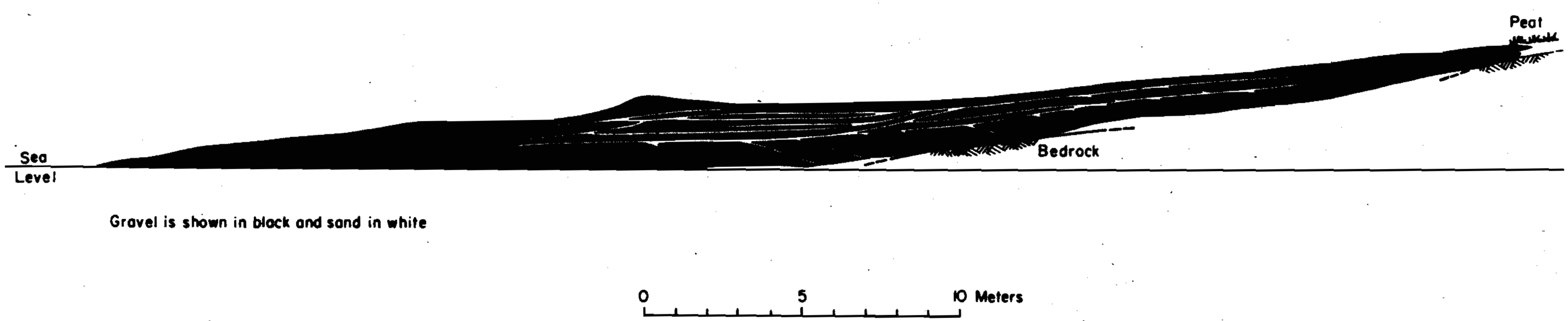

Figure 5.--Bedding of Ogotoruk Beach, Alaska

Lagoons

Lagoons fronted by barrier beaches in northwestern Alaska are largest in areas where the land surface is a plane sloping gently toward the sea. They are absent in areas where the coastal region is characterized by steep slopes. Profiles through the lagoons and adjacent offshore and land areas suggest that the lagoons were partly formed by the construction of barrier beaches following a rise of sea level to its present position. Steep scarps on the landward shores of some lagoons also indicate that some enlargement has been effected by thawing of tundra behind the lagoons.

Piston-core samples taken from the floors of the lagoons indicate that very little sedimentation has occurred in lagoons which do not contain the mouths of rivers. Mapsorrak Lagoon (lat 68°02' N.; long 165°22' W.) was studied in detail (fig. 6). Coarse sediment related to the barrier beach extends only a short distance into the lagoon. Typical cores from Mapsorrak Lagoon contain about 10 centimeters of olive-gray sandy mud overlying dark-gray clay. It is thought that the upper layer of sandy mud represents the lagoon deposit and that the lower clay remains from a colluvial soil which mantled the area before the last major rise of sea level about 5,000 years ago.

The lagoon water has a pH of about 7.4, and the lagoon sediment is somewhat acidic with a pH of approximately 6.3. Reducing conditions exist with respect to sulfate ion at the base of the section of recent sediments.

Currents in Mapsorrak Lagoon are almost wholly related to local wind conditions. Studies using current drogues indicate that the lagoon currents are parallel with the wind and have a velocity equal to about 2 percent of the wind velocity. Few surface eddies develop, and the principal

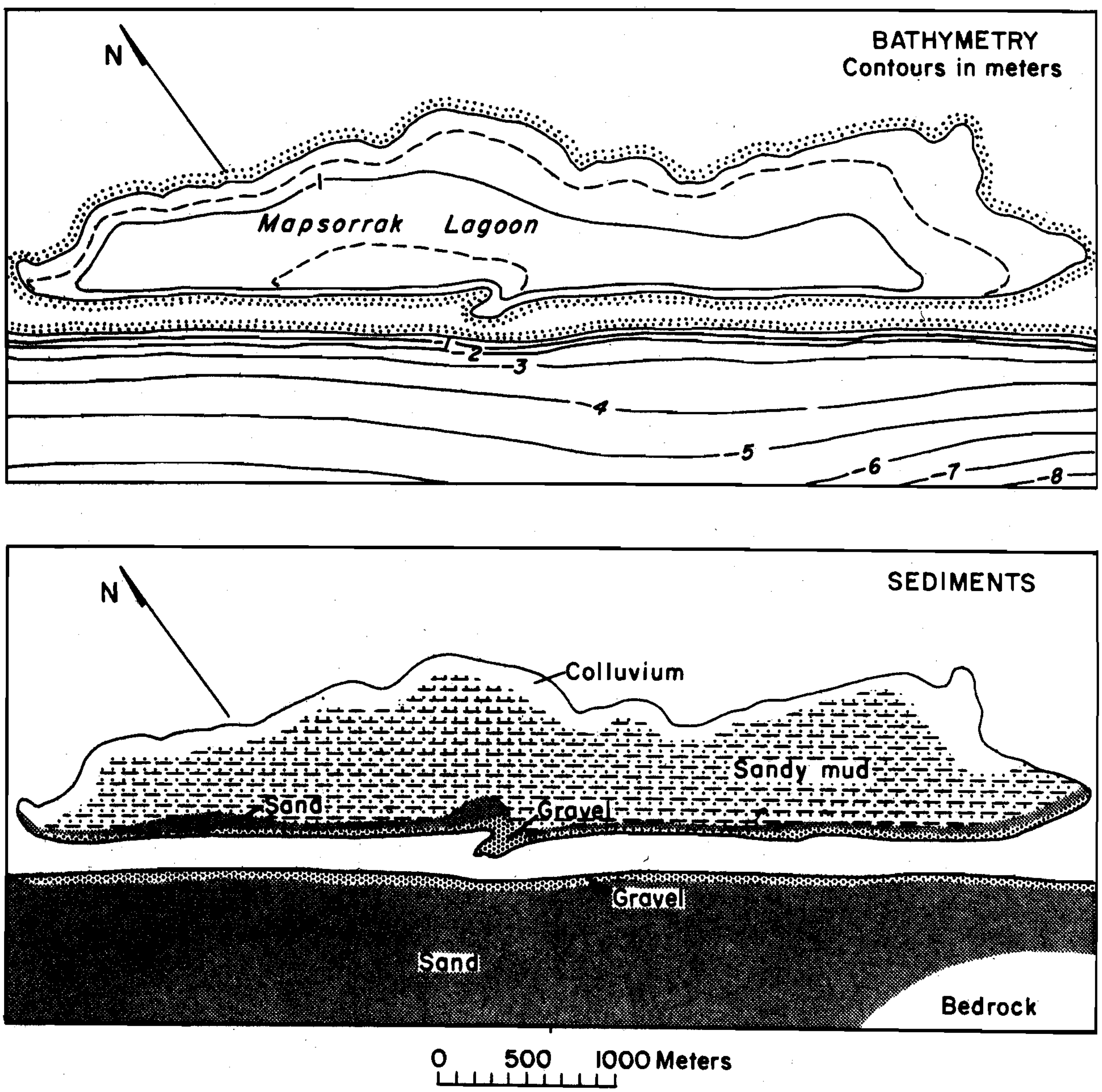

Figure 6.--Bathymetry and sediments of Mapsorrak Lagoon and the adjacent part of the Arctic Ocean

circulation seems to be the overturn of water on the leeward side accompanied by return along the floor of the lagoon.

Offshore

Sediments in the area offshore from Ogotoruk Beach have been described in an earlier report (Scholl and Sainsbury, 1959). In the nearshore area, the sediment related to the modern beach grades downward from gravel to a thin wedge of fine-grained sand at a depth of about 5 meters. Studies of sediment thickness in the Chukchi Sea made during 1960 by sonoprobe methods (David G. Moore, U. S. Navy Electronics Laboratory, oral communication) indicate that the thickness of Recent sediments on the floor of the sea ranges from 0 to 5 meters. This suggests that sedimentation is extremely slow on the floor of the Chukchi Sea and that the recent marine deposits probably were laid down during the transgressive phase of the sea, following the low stand of sea level which existed during the Wisconsin glacial stage.

Coastal processes

The principal difference between coastal processes in arctic regions and those in other parts of the world is the long period when the processes are arrested by the presence of pack ice. Breakup generally commences early in July, and the surf activity which follows usually lasts four months, ending for the year in October.

Effect of sea ice

Although the presence of a thick layer of sea ice adjacent to arctic beaches might be expected to affect strongly the sediments on the beaches, especially during the breakup period, this was shown not to be true during 1960. A special effort was made to observe the processes occurring during the spring breakup, and the pack ice was found to have surprisingly little effect on the beaches. The ice attains a thickness of more than 1.5 meters in this area, and it freezes fast to the sea floor to a distance of about 10 meters from the shore. Shearing then occurs between the fast ice and the floating ice. During breakup the shelf of fast ice along the shore tends to protect the beach from possible disturbance by the ice floes. Where the pack ice is moved strongly toward the land by currents and wind action, it overrides the protective belt of fast ice but only rarely impinges against the beach material itself. Aerial reconnaissance indicates that not more than 1 percent of the beach in this part of northwestern Alaska was disturbed by the movement of pack ice during the 1960 breakup.

Role of the kaimoo

The kaimoo is a phenomenon peculiar to arctic regions which has an important effect on coastal processes. It is an ice and gravel rampart built on the surface of arctic beaches and is extensively used by Eskimos as a smooth, flat sled trail (D. C. Foote, written communication, 1960). In October, when air temperatures fall below freezing, the surface of the beach freezes before ice begins to form on the sea. A portion of each wave which runs up on the beach freezes there, leaving a thin layer of ice. Gradually a bed of ice as much as a meter and a half thick, commonly containing thin beds of beach gravel, is built on top of the beach. The upper surface ultimately becomes nearly flat, and subsequent wave action can take place only against the resistant outer face of the kaimoo. The building of the kaimoo late in October ordinarily marks the end of effective wave action on the beach. Occasionlly a heavy fall storm may undermine the kaimoo and disrupt it, but the development of the kaimoo is soon followed by the formation of sea ice which definitely terminates surf activity for the year.

Seaward and landward movement of beach material

Two directions of movement of material take place on beaches, movement normal to the shoreline and movement along the shore. By far the more important in terms of the amount of material transported is that movement which takes place toward the sea and then back again toward the land under changing surf conditions. During a single storm, millions of tons of material are transported in this way. Under very strong surf conditions, the beach material may be almost entirely removed and deposited as a bar near the breaking point of the waves. On August 9, 1960, Ogotoruk Beach was lowered nearly a meter by waves 1.4 meters high, but the high surf unfortunately prevented study of the shape of the offshore bar which was probably formed. If an offshore bar had been formed, it was destroyed during the waning phases of this storm, and the material was largely restored to the beach. Figure 7 illustrates different profiles of Ogotoruk Beach during calm and moderate surf conditions, when it was possible to work offshore.

In spite of the large volume of sediment handled during onshore and offshore transport of beach material, movement in the two directions ordinarily balances, and the position of the shoreline, therefore, is not permanently altered by this type of motion.

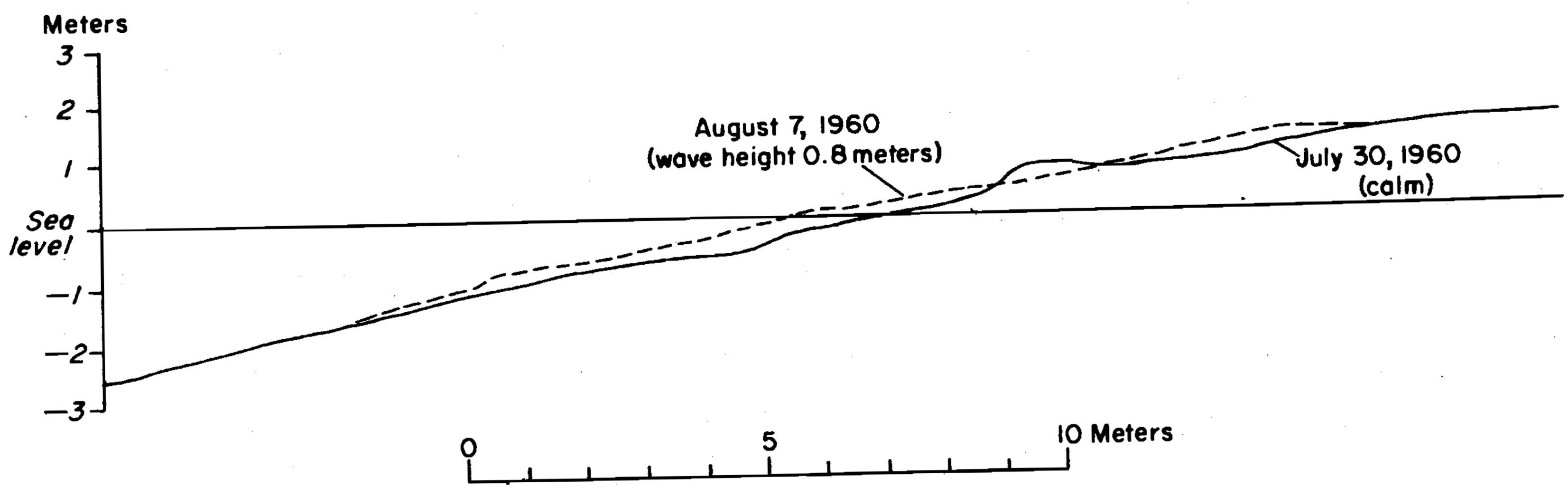

Figure 7.--Profile of Ogotoruk Beach during a calm period and during waning moderate surf conditions

Alongshore transport

The movement of beach material parallel with the shore is especially important in studying coastal processes because such drift can cause permanent changes in the configuration of the coastline. Wave attack at an angle is the principal cause of the alongshore transport as longshore water currents parallel with the shore are too weak to cause movement of material of the coarse grain size characteristic of beaches in northwestern Alaska. Surf characteristics for the 1960 surf year are given in table 3. The rate of alongshore movement of beach material is chiefly dependent upon the wave height and the surf angle--the angle between the wave crest and the beach. The rate of movement during a given set of surf conditions is shown by the following relation in which the empirical constants for beaches in northwestern Alaska were evaluated by plane-table mapping of the growth of a spit across the outlet of a lagoon; the outlet was suddenly opened following a heavy rain and then slowly closed by growth of the spit (Moore and Cole, 1960):

$$Q = 2350\ h^{2.5} \sin\phi \cos\phi$$

where

Q = alongshore transport in cubic meters per day

h = wave height in meters

ϕ = surf angle in degrees

Alongshore transport toward the west and toward the east are almost exactly balanced at Ogotoruk Beach, and even a compilation of daily transport for the entire year is not necessarily indicative of average net transport for the area. During 1960 the total net alongshore transport for the surf year was nearly 30,000 cubic meters to the west (table 3). But

Table 3.--Surf characteristics at Ogotoruk Beach, Alaska, 1960

Date[1]	Wave height (meters)	Wave period (seconds)	Wave length (meters)	Surf angle[2] (degrees; direction)	Water temperature (° C.)	Longshore current (centimeters per second; direction)	Median grain diameter[3] (millimeters)	Alongshore transport[4] (cubic meters; direction) Daily	Cumulative
July									
	Sea ice left shore July 1; first effective surf July 5.								
5	0.2	2.5	5	35 E.	1	5 E.	12.6	20 E.	20 E.
6	0.2	2.7	5	25 E.	1	0	12.3	16 E.	36 E.
7	0.3	2.6	5	40 E.	2	0	10.3	57 E.	93 E.
8	0.2	2.6	5	5 E.	2	9 E.	6.2	4 E.	97 E.
9	0.2	3.3	5	5 E.	4	8 E.	9.1	4 E.	101 E.
10	0.6	5.0	10	5 W.	3	20 W.	3.5	57 W.	44 E.
11	0.5	4.8	10	5 E.	4	15 E.	3.9	36 E.	80 E.
12	0.4	4.3	5	10 E.	5	11 E.	10.2	41 E.	121 E.
13	0.5	4.0	10	20 E.	6	4 W.	13.3	133 E.	254 E.
14	0.2	2.7	5	35 E.	7	20 E.	7.4	20 E.	274 E.
15	0.1	3.5	5	5 E.	5	15 W.	6.1	1 E.	275 E.
16	0.0	--	--	--	5	4 E.	4.6	0	275 E.
17	0.2	5.5	5	10 W.	5	5 W.	6.1	7 W.	268 E.
18	0.3	3.5	10	5 W.	7	3 W.	15.5	10 W.	258 E.
19	1.4	6.0	20	5 E.	7	23 E.	5.7	473 E.	731 E.
20	0.3	4.0	10	5 E.	8	1 E.	7.2	10 E.	741 E.
21	0.0	--	--	--	8	0	21.0	0	741 E.
22	0.0	--	--	--	9	0	32.5	0	741 E.
23	0.1	6.5	5	0	10	0	5/	0	741 E.
24	0.1	5.0	5	0	8	5 E.	5/	0	741 E.
25	0.0	--	--	--	7	0	18.5	0	741 E.
26	0.1	7.1	5	5 E.	9	3 E.	17.0	1 E.	742 E.
27	0.2	4.5	5	10 E.	13	2 W.	0.8	7 E.	749 E.
28	0.1	4.5	5	0	13	0	0.2	0	749 E.
29	0.0	--	--	--	13	0	0.2	0	749 E.
30	0.0	--	--	--	9	0	6.1	0	749 E.
31	0.0	--	--	--	10	0	0.2	0	749 E.

Table 3.--Surf characteristics at Ogotoruk Beach, Alaska, 1960 - continued

Date[1]	Wave height (meters)	Wave period (seconds)	Wave length (meters)	Surf angle[2] (degrees; direction)	Water temperature (° C.)	Longshore current (centimeters per second; direction)	Median grain diameter[3] (millimeters)	Alongshore transport[4] (cubic meters; direction) Daily	Cumulative
August									
1	0.1	5.5	15	5 E.	4	11 E.	5.8	1 E.	750 E.
2	0.1	4.3	10	5 E.	4	0	3.3	1 E.	751 E.
3	0.3	4.1	10	15 E.	8	6 E.	--	29 E.	780 E.
4	0.0	--	--	--	9	0	11.9	0	780 E.
5	0.4	4.4	10	25 E.	10	25 W.	8.8	91 W.	689 E.
6	0.3	4.4	10	20 W.	11	6 W.	13.9	37 W.	652 E.
7	0.2	4.4	10	10 E.	11	2 W.	17.9	7 E.	659 E.
8	1.2	4.4	15	5 E.	11	29 E.	7.3	320 E.	979 E.
9	1.4	5.8	15	5 E.	11	8 E.	4.4	472 E.	1451 E.
10	1.1	5.5	10	0	12	0	4.4	0	1451 E.
11	0.6	5.5	15	0	11	4 E.	2.5	0	1451 E.
12	0.2	5.0	5	0	12	1 W.	0.9	0	1451 E.
13	0.2	7.5	5	0	12	4 W.	0.6	0	1451 E.
14	0.1	--	--	0	--	--	--	0	1451 E.
15	0.1	7.0	5	0	9	5 W.	6.9	0	1451 E.
16	0.1	7.1	5	0	9	0	3.0	0	1451 E.
17	0.1	5.5	5	0	9	0	13.3	0	1451 E.
18	0.1	5.3	15	5 E.	9	3 E.	9.2	1 E.	1452 E.
19	0.1	5.5	10	0	9	0	5.1	0	1452 E.
20	0.1	5.0	5	5 E.	10	8 E.	5.2	1 E.	1453 E.
21	0.1	6.0	10	15 E.	10	0	8.7	2 E.	1455 E.
22	0.2	2.5	5	20 E.	10	6 E.	5.8	13 E.	1468 E.
23	0.5	3.5	5	5 E.	11	5 E.	9.2	36 E.	1504 E.
24	1.8	5.5	25	0	11	16 W.	5.0	0	1504 E.
25	0.9	5.0	15	5 W.	11	29 W.	2.6	156 W.	1348 E.
26	0.5	7.0	30	20 E.	--	28 E.	6.7	133 E.	1481 E.
27	0.8	6.0	20	25 E.	--	42 E.	3.4	514 E.	1995 E.
28	0.2	7.0	20	15 E.	--	3 W.	--	11 E.	2006 E.
29	0.0	--	--	--	7	3 W.	5.1	0	2006 E.
30	0.1	5.0	5	0	--	0.	2.6	0	2006 E.
31	0.0	--	--	0	3	3 W.	5.7	0	2006 E.

Table 3.--Surf characteristics at Ogotoruk Beach, Alaska, 1960 - continued

Date[1]	Wave height (meters)	Wave period (seconds)	Wave length (meters)	Surf angle[2] (degrees; direction)	Water temperature (° C.)	Longshore current (centimeters per second; direction)	Median grain diameter[3] (millimeters)	Alongshore transport[4] (cubic meters; direction) Daily	Alongshore transport[4] Cumulative
September									
1	0.0	—	—	—	9	0	11.5	0	2006 E.
2	0.1	6.0	20	5 E.	8	10.E.	10.0	1 E.	2007 E.
3	0.0	—	—	—	—	6 E.	—	0	2007 E.
4	0.2	4.5	—	5 E.	—	0	—	4 E.	2011 E.
5	0.0	—	—	—	—	0	—	0	2011 E.
6	0.3	2.5	—	5 W.	—	14 W.	[illegible]	10 W.	2001 E.
7	0.3	4.4	—	0	—	5 E.	—	0	2001 E.
8	0.5	3.3	—	10 W.	—	21 W.	—	71 W.	1930 E.
9	0.2	4.0	—	0	—	0	—	0	1930 E.
10	0.0	—	—	—	—	0	—	0	1930 E.
11	0.0	—	—	—	—	0	—	0	1930 E.
12	0.0	—	—	—	6	9 E.	—	0	1930 E.
13	0.2	—	—	—	6	0	—	0	1930 E.
14	0.3	4.0	—	30 E.	4	3 E.	—	50 E.	1980 E.
15	0.9	4.5	—	20 W.	7	15 W.	—	578 W.	1402 E.
16	0.6	5.0	—	45 E.	6	38 E.	—	326 E.	1728 E.
17	0.2	1.0	—	0	4	5 E.	—	0	1728 E.
18	0.6	4.0	—	20 W.	4	30 W.	—	210 W.	1518 E.
19	0.6	3.9	—	30 W.	4	37 W.	—	282 W.	1236 E.
20	0.0	—	—	—	3	0	—	0	1236 E.
21	0.0	—	—	—	3	0	—	0	1236 E.
22	0.0	—	—	—	2	0	—	0	1236 E.
23	0.0	—	—	—	2	0	—	0	1236 E.
24	0.0	—	—	—	2	0	—	0	1236 E.
25	1.2	5.0	—	20 W.	3	23 W.	—	1186 W.	50 E.
26	1.5	4.0	—	10 W.	4	36 W.	—	1105 W.	1055 W.
27	0.6	4.0	—	45 E.	4	43 E.	—	326 E.	729 W.
28	0.3	4.6	—	10 W.	5	3 W.	—	20 W.	749 W.
29	1.8	4.0	—	30 W.	4	37 W.	—	4417 W.	5166 W.
30	0.9	1.0	—	20 W.	4	15 W.	—	578 W.	5744 W.

Table 3.--Surf characteristics at Ogotoruk Beach, Alaska, 1960 - continued

Date[1]	Wave height (meters)	Wave period (seconds)	Wave length (meters)	Surf angle[2] (degrees; direction)	Water temp-erature (° C.)	Longshore current (centimeters per second; direction)	Median grain diameter[3] (millimeters)	Alongshore transport[4] (cubic meters; direction) Daily	Cumulative
October									
1	0.9	2.3	--	20 W.	4	5 W.	--	578 W.	6322 W.
2	1.2	4.0	--	20 W.	4	23 W.	--	1186 W.	7508 W.
3	1.8	4.2	--	10 W.	4	30 W.	--	1748 W.	9256 W.
4	0.0	--	--	--	4	0	--	0	9256 W.
5	0.0	--	--	--	3	0	--	0	9256 W.
6	0.0	--	--	--	2	0	--	0	9256 W.
7	0.0	--	--	--	1	0	--	0	9256 W.
8	0.3	3.6	--	20 W.	1	2 W.	--	37 W.	9293 W.
9	0.0	--	--	--	2	0	--	0	9293 W.
10	0.0	--	--	--	1	0	--	0	9293 W.
11	0.0	--	--	--	1	0	--	0	9293 W.
12	0.0	--	--	--	1	0	--	0	9293 W.
13	0.0	--	--	--	0	0	--	0	9293 W.
14	0.9	4.0	--	20 W.	0	10 W.	--	578 W.	9871 W.
15	1.8	3.6	--	30 W.	1	30 W.	--	4417 W.	14288 W.
16	1.0	--	--	20 W.	--	--	--	755 W.	15043 W.
17	2.0	--	--	15 W.	--	--	--	3340 W.	18383 W.
18	0.3	--	--	25 E.	--	--	--	44 E.	18339 W.
19	2.0	--	--	25 W.	--	--	--	5094 W.	23433 W.
20	2.0	--	--	25 W.	--	--	--	5094 W.	28527 W.
21	0.1	--	--	0	--	--	--	0	28527 W.

Sea water freezing on the beach as a kaimoo ended effective surf activity October 21, 1960.

1/ Data collected each day at 7:30 p.m.
2/ The surf angle is the acute angle between the wave crest and the beach; the direction is the approximate compass direction toward which the angle is open.
3/ Sediment samples were collected from the midpoint of the belt alternately covered and uncovered by the wave swash.
4/ Alongshore transport of beach sediment was calculated using the relation given in the text.
5/ Sediment sample has bimodal size distribution: pebbles approximately 5 cm in diameter enclosed in a 0.2 mm sand matrix.

studies of the distribution of older beach deposits at Cape Krusenstern suggest that the net alongshore transport for about the past 400 years has been toward the east. Analysis of the distribution of beach deposits at Cape Krusenstern indicates that prior to this period net movement to both the east and the west has occurred at various times during the past 5,000 years.

Simultaneous observations of surf characteristics over a broad area are a valuable way of evaluating the coastal processes operating in an area. Figure 8 gives the most important surf characteristics during southeast and northwest winds at several localities along approximately 200 kilometers of coastline. The regional pattern of differences in the alongshore transport are shown by the diagrams. Because of the local effect of the topography on the wind, wind velocities and directions are given at an altitude of 1,000 meters as measured at the Chariot test site. Wind at this altitude may be parallel with the wind which generates waves at sea, and the validity of this supposition is supported by the compatible surf characteristics.

Figure 8 shows that during southeast winds, deposition occurs at Point Hope and probably also occurs at Cape Krusenstern. During northwest winds erosion occurs at Point Hope and deposition occurs at Cape Krusenstern. Flexures of the coastline between these two points are not sufficient to cause permanent deposition by alongshore transport regardless of the wind direction. All the intermediate beaches such as that fronting the Chariot site may be said to be in a steady-state condition in which neither significant permanent erosion nor permanent deposition occurs.

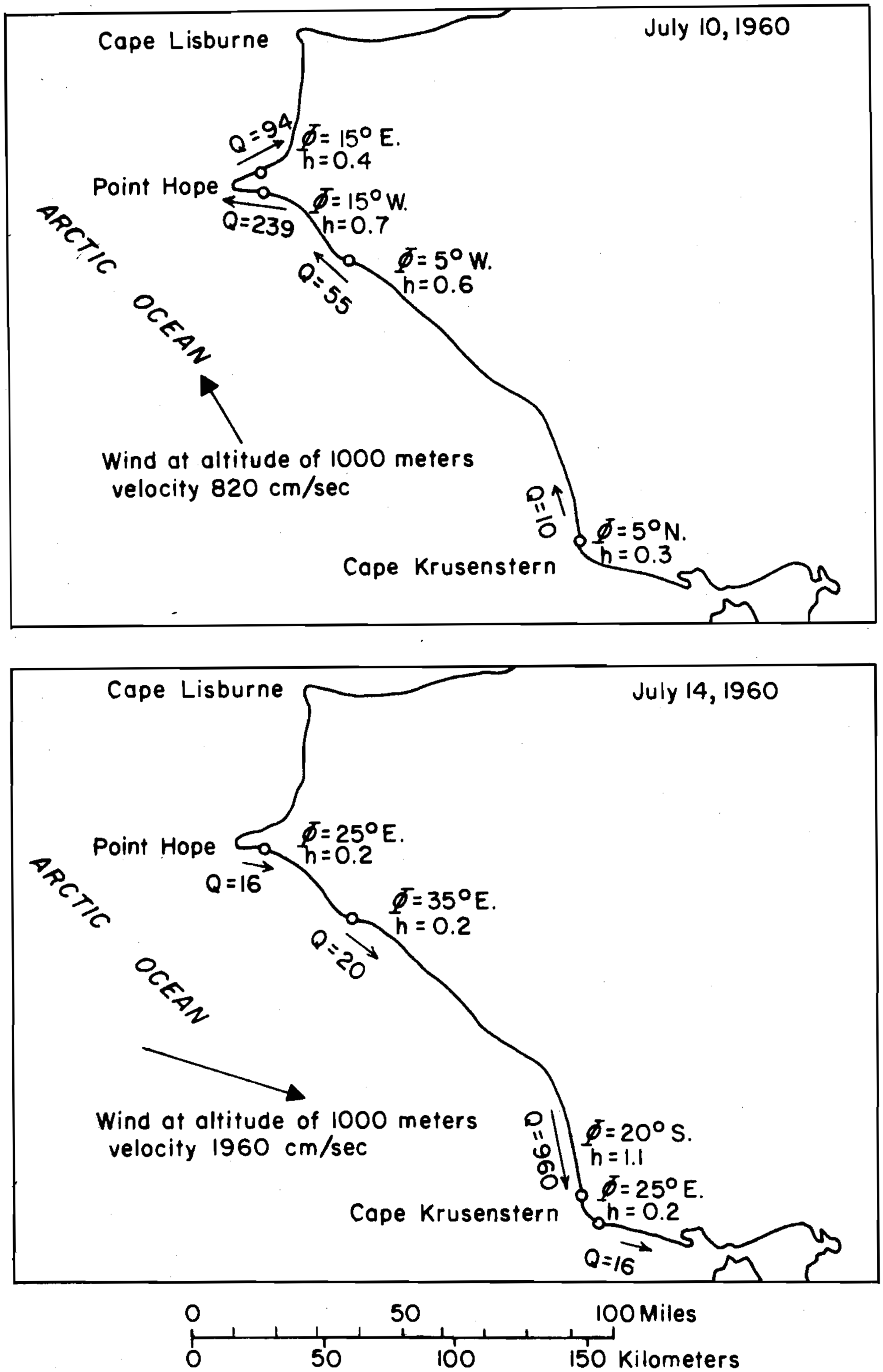

Figure 8.--Simultaneous surf characteristics in northwestern Alaska showing the pattern of alongshore transport of beach material during southeast and northwest winds. Ø = surf angle and direction in degrees; h = wave height in meters; Q = calculated alongshore transport in cubic meters per day.

Shoreline history

The steady-state beaches such as Ogotoruk Beach are not useful for interpreting the past history of the area because the record of past events are piled one on top of another in a complex fashion. At Point Hope and Cape Krusenstern, however, a unique and valuable record has been preserved. The earliest well preserved beaches in northwestern Alaska are those of Sangamon age ranging from 100,000 to 63,000 years old (Rosholt and others, in press). Two beaches of Sangamon age are represented at Point Hope and are separated by a period in which sea level stood below its present position. Altitude of the beach gravel ranges between 3 and 12 meters above sea level, and sea level stood about 8 meters above its present position during Sangamon time (fig. 9, upper map).

A collection of fossils from the beach of Sangamon age near Cape Krusenstern at lat 67°17' N., long 163°49' W., supports the Sangamon age assignment. The following forms were identified and interpreted by F. Stearns MacNeil, U. S. Geological Survey:

Gastropoda:

Natica janthostoma Deshayes

Neptunea sp.

Pelecypoda:

Serripes groenlandicus (Bruguiére)

Spisula cf. *S. voyi* (Gabb)

Protothaca adamsi (Reeve)

Tellina (*Peronidia*) *lutea* Gray

Macoma cf. *M. calcarea* Gmelin

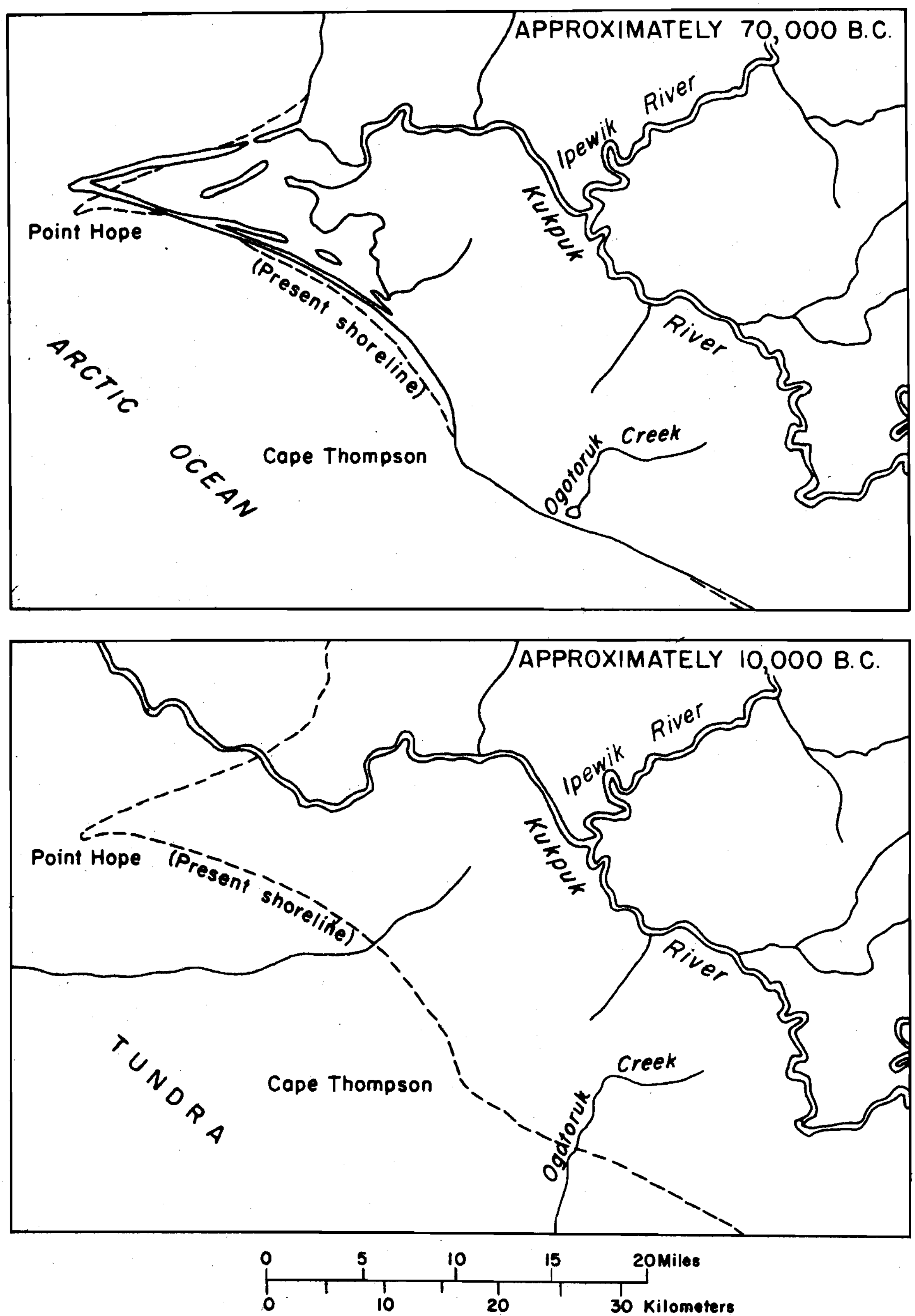

Figure 9.--Shoreline history of the Cape Thompson area

According to MacNeil, the most significant specimen in the assemblage is the Protothaca adamsi. It is the only species in the collection which seems to have invaded the arctic only once, during Sangamon time, and to have abandoned it completely. This species now lives from central to northern Japan. Its present confinement to this more southern latitude does not necessarily indicate that the climate was warmer in northwestern Alaska during Sangamon time than at present but indicates only that this species has not migrated back into the arctic again since the last rise of sea level. The general aspect of the fossil assemblage suggests that climatic conditions during Sangamon time were approximately comparable to those at present.

Dating by the radiocarbon method has been used to provide a minimum age for the beach gravel of Sangamon age. A sample of peat which is younger than the gravel and overlies it at lat 67°12' N., long 163°44' W., was analyzed in the radiocarbon laboratory of the Berne Historical Museum, Switzerland. The age of the peat is 26,000 ± 400 years old, which is compatible with the Sangamon age assignment of the underlying gravel.

Following the high stand of sea level during Sangamon time, the sea retreated from the Chukchi Sea to maintain the earth's water balance during Wisconsin time when continental glaciers were widespread. During this period the Chukchi Sea was a broad, tundra-covered plain (fig. 9). The absence of the ameliorating presence of the sea probably imposed colder winters and warmer summers on the area. With the waning of the continental glaciers, however, sea level rose again and reached approximately its present position about 5,000 years ago.

Following the establishment of the present coastal regimen in the area, extensive deposits of beach ridges have been formed at Point Hope and Cape Krusenstern. The steady-state beaches along the remainder of the coastline have served as paths for the movement of beach material from its source areas to these points of deposition. The beach deposits at Point Hope and Cape Krusenstern provide a record of the fluctuations of sea level which have occurred during the past few thousand years (Moore, 1960). The evidence from the ridges indicates that sea level rose about 3 meters during the past 5,000 years and that the rise may have been characterized by minor fluctuations with amplitudes of 1 to 2 meters. The highest stand of sea level since the Wisconsin glacial stage was attained in the 19th century.

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INTERIM REPORT ON GEOTHERMAL STUDIES, OGOTORUK VALLEY, NORTHWEST ALASKA

by

Arthur H. Lachenbruch, Gordon W. Greene and B. Vaughn Marshall

Introduction

During the summer of 1960 two additional holes were drilled to assist in the geothermal studies of lower Ogotoruk Creek valley. Temperatures measured in these holes will provide additional data, and, as predicted, the initial data are more reliable because damage to the cables by caving of the holes has been prevented by installation of casing. Both holes pass below the 0°C isotherm, the bottom of permafrost as presently defined (Muller, 1945). Figure 2 shows the locations of all test holes.

Temperatures were measured by U.S.G.S. personnel during the summer, and by Mr. William Lyons, the Holmes and Narver, Inc. representative at Chariot, since then. Although it is possible from these few data to predict the equilibrium (or predrilling) temperatures, further analysis is required to separate the thermal anomalies resulting from changes in shoreline location, climatic change and the presence of the lagoon. At this time it appears that the new data will provide the information needed for a more comprehensive quantitative treatment of the problems outlined qualitatively in the previous reports (Lachenbruch and Greene, 1960, and Lachenbruch, 1960).

Hole Dog, located approximately 1,300 yards from the ocean, was drilled to a depth of 1,202 feet. Two U.S.G.S. thermistor cables with a total of 41 temperature-sensing elements were installed in this hole on August 9, 1960.

Hole Charlie, drilled at a point approximately 100 yards from the ocean, was bottomed at a depth of 1,002 feet. Three thermistor cables, two made by the U.S.G.S. and one by SIPRE, were placed in Hole Charlie on September 2, 1960.

By prior agreement only data obtained from the U.S.G.S. cables are used in this report.

Equilibrium temperatures and dissipation of the drilling disturbance

The equipment and drilling techniques used by SIPRE resulted in a drilling disturbance many times less than would be obtained by using more conventional methods. With a smaller disturbance it is possible to make reliable predictions of the equilibrium temperatures at various depths using a shorter period of observation.

The method of obtaining equilibrium temperatures in a drill hole is described in detail elsewhere (Lachenbruch and Brewer, 1959). Briefly, a plot of successive temperature measurements at a single depth vs. log $\frac{t-s}{t}$ should yield a straight line. Here t is the time elapsed since the drill bit first reached the depth in question, and s is the duration of drilling at a particular depth. Extrapolation of this line to infinite time ($\frac{t-s}{t} \cong 1$) yields the equilibrium temperature.

Figure 10 illustrates the changes in the postdrilling temperature at a depth of approximately 300 feet in each of the four holes. The thermal anomaly produced by drilling is shown to be considerably less in Holes Charlie and Dog than in Holes Able and Baker. It is also apparent that Holes Charlie and Dog are closer to their equilibrium temperatures at present than are Holes Able and Baker, despite the fact that Able and Baker were drilled a year earlier.

The temperatures at a depth of 300 feet in Hole Charlie are increasing slightly as equilibrium is approached. This condition prevails at depths greater than 200 feet in Hole Charlie and 900 feet in Hole Dog. At these

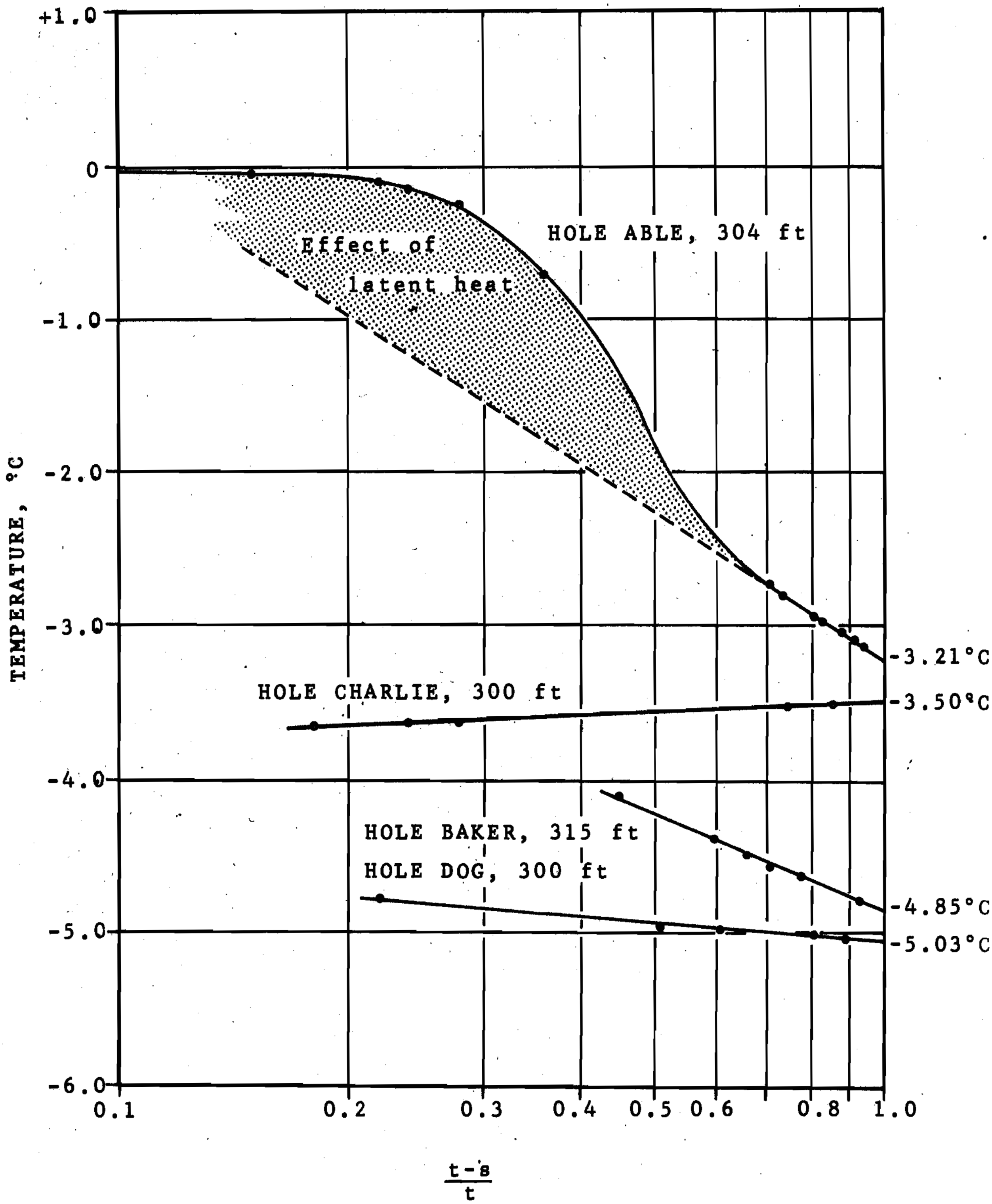

Figure 10. Dissipation of the thermal anomalies due to drilling at approximately the 300-foot depths in each hole

depths a "negative" anomaly was created by the refrigerated drilling fluid being colder than the ambient subsurface temperatures.

The complicating effect of latent heat in the aqueous drilling fluid and wall rock is illustrated by the curvature in the logarithmic cooling curve for Hole Able. As t becomes large with respect to s, the effect of latent heat becomes negligible and the method of linear extrapolation may be used.

Estimated equilibrium temperatures in the four holes are shown by the solid lines in figure 11. Permafrost thicknesses at Holes Able and Baker have been suggested by downward extrapolation of the profile from 600 feet in Hole Able and at 465 feet in Hole Baker. These extrapolations are highly uncertain, and the broken lines cannot be compared for reliability with the solid ones which are drawn from actual temperature measurements. The extrapolation at Hole Baker is controlled largely by results of a careful study of a partially damaged thermistor at the 1,015-foot depth.

Seasonal temperature changes at the surface are propagated downward with attenuated amplitude, and prevent the establishment of an equilibrium gradient near the surface. The depth to which seasonal changes may be detected depends upon the amplitude of the temperature change from summer to winter, the physical properties (conductivity, specific heat, and density) of the rock, and the sensitivity of the measuring instruments. Thermal measurements at depths of less than 65 feet at Ogotoruk Creek can be expected to show the effects of seasonal temperature changes at the surface.

Frequent observations (at least weekly between depths of 5 and 90 feet) over a period of a year may be averaged to give the mean annual temperatures at the various depths. A geothermal profile of mean annual temperatures can then be used to extend the equilibrium geothermal profile closer to the

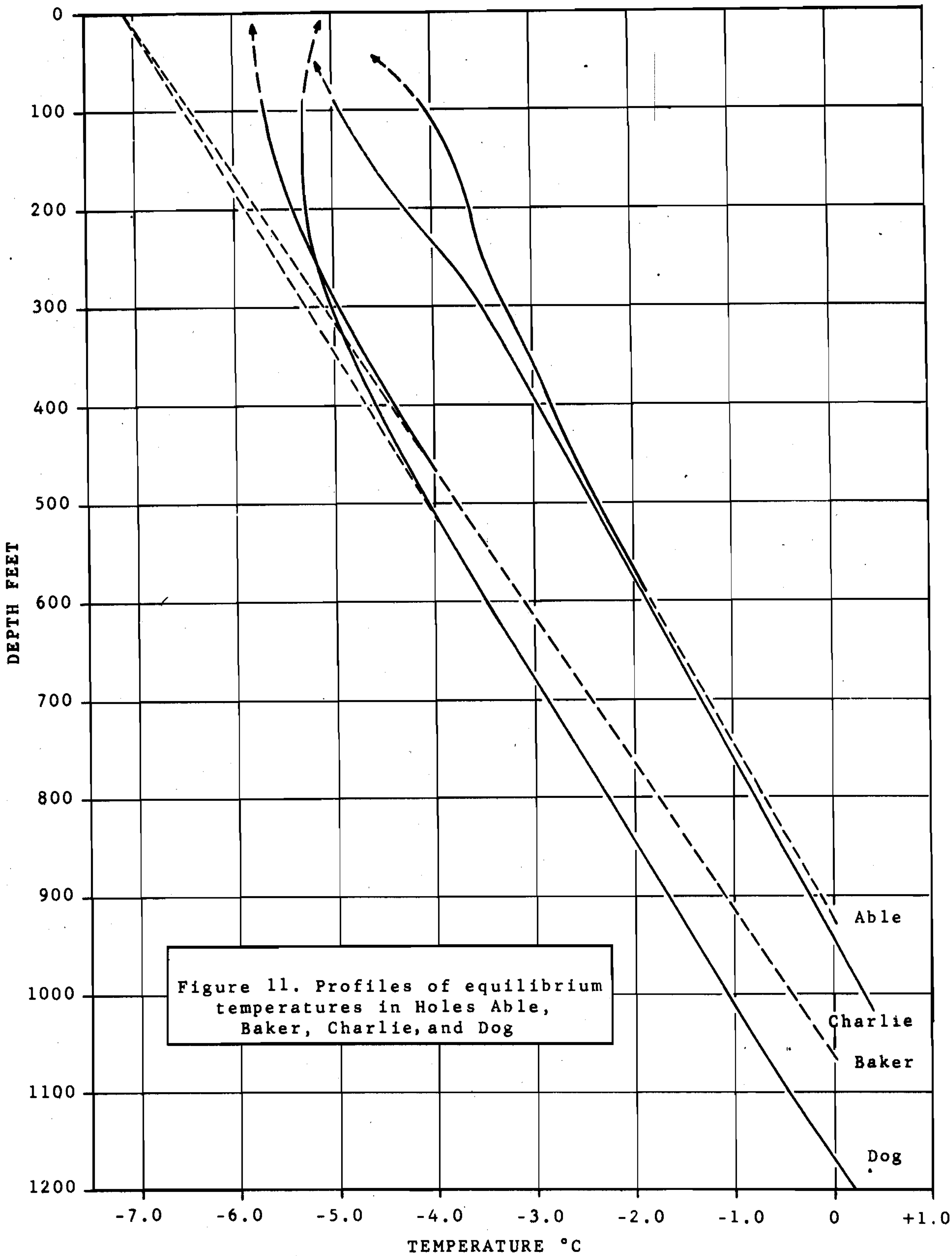

Figure 11. Profiles of equilibrium temperatures in Holes Able, Baker, Charlie, and Dog

surface. But because of differences in the mean surface temperatures from one year to the next, variations will be found in the mean annual subsurface temperatures from year to year. A temperature change at the surface is propagated into the earth at a rate dependent upon the physical properties of the rock. Thus, temperatures at depths of 30 and 60 feet depend respectively upon the surface conditions 6 and 12 months prior to the observation. Therefore, temperatures at different depths in a mean annual temperature profile reflect conditions of different one-year periods. Nevertheless, the method is very useful and the thermistors at depths of 100 feet or less in Holes Charlie and Dog are being read weekly to obtain this information.

Recent climatic change

Curvature in the upper 500 feet of the geothermal profile of Hole Dog shows that temperatures at depth are not in equilibrium with the present thermal regime at the surface. This curvature is similar to, but more pronounced than, that noted earlier in Hole Baker. A systematic climatic change which has increased the mean temperature of the ground surface seems to be responsible for the curvature of the profiles.

When the undisturbed profile below 500 feet at Hole Dog is extrapolated to the surface, a mean ground surface temperature, of slightly under -7°C is indicated before the start of the climatic change. The best recent information from Hole Baker yields a similar, though much less reliable, value. The present mean ground surface temperature based on continuation of profiles to the surface is about -5.8°C at Hole Baker and -5.1°C at Hole Dog (the mean annual air temperature at the surface can be expected to be roughly 2° or 3°C lower). Thus present data suggest a total increase in mean surface temperature of about 2°C at Hole Dog and about 1.3°C at Hole Baker. As pointed out elsewhere (Lachenbruch, 1960) this does not necessarily imply that the mean annual air temperature has increased, as subtle changes in other climatic parameters could account for the trend. Although this change in mean ground-surface temperature might not, in itself, be important to local biological systems, it is not unlikely that it was accompanied by marked changes in other more biologically significant parameters, such as amplitude of seasonal temperature variation or quantity of winter snow or summer rain. The mean ground-surface temperature just happens to be the quantity accessible to a geothermal analysis.

An approximation of the length of time since the start of the climatic change, and the rate at which it has occurred, may be made by calculating the values of $\Delta\Theta/B$ and $x/2\sqrt{\alpha t}$ for various depths in each hole. Here $\Delta\Theta$ is the total change in earth temperature at a particular depth, x, B is the total change of the mean ground-surface temperature, α is the thermal diffusivity, and t is the time since the start of climatic change. For each depth a single value of $\Delta\Theta/B$ and several values of $x/2\sqrt{\alpha t}$ are obtained. These points are fitted to theoretical curves of $\Delta\Theta/B$ vs $x/2\sqrt{\alpha t}$ that are calculated using various assumptions as to the nature of the climatic change. A step increase in mean ground-surface temperature, a linear increase, and an increase proportional to the square root of t have been investigated. All assumptions agree that the climatic change started between 50 and 120 years ago, but the rate at which the change has occurred is not clear as yet. The change is roughly equivalent to a net gain by the earth of about 50 cal/cm^2/ yr over the past six or eight decades.

In calculating $x/2\sqrt{\alpha t}$ an average value for α of 0.01 cm^2 / sec was used. It is likely that thermal diffusivity in Hole Dog is greater than at Hole Baker, as indicated by the fact that the effects of climatic warming at the surface have penetrated to greater depths at Hole Dog. The difference in thermal diffusivities must be considered in a refined solution of the climatic change problem.

Comments on surface microenvironment

The difference in mean ground-surface temperature over the half mile or so between Hole Dog and Hole Baker seems to be real, although the exact value of the difference, 0.7°C, might be adjusted slightly after further analysis. It is less certain, but highly suggestive, that the mean ground-surface temperatures at the two sites were not different prior to the climatic change. Thus it seems likely that whatever microenvironmental difference is responsible for the present disparity between the surface temperatures at Hole Baker and Hole Dog probably evolved during the last century, and might well be in the process of change today. As an example, the surface in the vicinity of Hole Dog has high microrelief with *Eriophorum* tussocks interspersed with bare mineral soil. At Hole Baker the microrelief is less extreme and the vegetal mat more continuous. If the rough surface at Hole Dog traps more drifting snow, this could account for the difference (Lachenbruch, 1959, p. 28-30). The existing data could then be interpreted as an indication that the extreme microrelief developed recently near Hole Dog, perhaps as a result of the climatic change. Several other possible causes can be mentioned, but the identification of the most likely factors is best left to the biological students of the microenvironment.

Measurements of thermal conductivity

The drilling techniques used by SIPRE made it possible to recover core samples in their natural state. These frozen cores have been transported and stored in refrigerated chests so that measurements of their physical properties will be as reliable as possible. Thermal conductivity tests of the specimens have been delayed awaiting the delivery of an electronic recorder especially designed for the work.

Thermal conductivity measurements on a thawed core sample from Hole Baker yielded values averaging about 5.25×10^{-3} cal/cm sec °C. When the sample was frozen and contained all of its natural moisture, it is likely that its conductivity was slightly greater.

During September 1960 several in place determinations of thermal conductivity were made in outcrops of the Tiglukpuk formation using the probe described by Lachenbruch (1957).

Thawed mudstones gave surprisingly uniform results (5.13, 5.16, and 5.18 cal/cm sec °C). An in place test on thawed mudstone fault-breccia containing 5.5 percent moisture gave a value of 3.27 cal/cm °C sec. These values are useful for computing surficial thermal effects and will provide an interesting comparison with data obtained in the laboratory from frozen core samples.

Earth heat flow

The flow of heat from the earth's interior is given by the product of the geothermal gradient at depth and thermal conductivity. In measuring the temperature gradient, however, the complicating effect of horizontal temperature gradients produced by nearby topographic relief or bodies of water must be considered.

A preliminary examination of terrain and ocean corrections required at Holes Baker and Dog shows them to be very small. Below 500 feet the uncorrected geothermal gradient in Hole Dog is 18.8°C/km, while at the same depths in Hole Baker only a rough estimate of 20° to 21°C/km is possible. These values differ by approximately 10 percent and could indicate differences in thermal conductivity in the two holes.

A preliminary calculation based on these geothermal gradients and the thermal conductivity values from Baker core yields a natural earth heat flow in the neighborhood of 10^{-6} cal/cm^2 sec. This is close to the worldwide average, or "normal" heat flow. Although this amounts to only 30 or 40 cal/cm^2 yr (enough to melt $\frac{1}{2}$ cm of ice) it is a quantity of fundamental importance in theoretical geophysics. No satisfactory determinations have been made in the entire North American Arctic. Contrary to the present result, it has been suggested (Misener, 1955) that heat flow in the Arctic is anomalously large.

Thermal effects of the ocean and lagoon

In the previous report it was shown that temperatures in Hole Baker can be materially affected by the ocean only if the ocean has been at or near its present location for longer than 10,000 years. Temperatures in Hole Dog, which is located a greater distance inland, can be considered to be unaffected by the presence of the ocean. Therefore, it is possible to separate the thermal anomaly produced by the ocean at Hole Charlie by subtracting temperatures at given depths in Holes Baker and Dog from the temperatures at the same depths in Hole Charlie (solid lines, figure 12). Only the upper part of the profile for Baker is represented because reliable data are lacking at depth.

The broken lines in figure 12 represent theoretical values of what this difference between Hole Charlie and the inland holes would be had the shoreline moved rapidly to its present position at various times in the past. They are based upon an assumed thermal diffusivity of 0.01 cm^2 /sec, a mean annual ground-surface temperature, prior to the recent climatic change of

-7.1°C, and a mean sea-bottom temperature of +0.9°C. The latter is based on sea-bottom temperatures off Cape Prince of Wales, kindly supplied by Gene L. Bloom, U. S. Navy Electronics Laboratory (written communication, 1960). The mean bottom temperature determined by M. C. Brewer off Barrow is about -0.5°C (written communication, 1958).

Figure 12 shows clearly that the earth is not in thermal equilibrium with the present shoreline, for if it were, the solid lines would coincide with the broken line marked $t+\infty$. The simple model depicted suggests that the best description of the process in terms of a single rapid transgression would be that it occurred some 2,000 to 5,000 years ago. (If further analysis indicates that the transgression was gradual, the date of its initiation would be earlier). The solid curves diverge in the upper 300 feet, and which one is appropriate to the present analysis depends on whether the surficial regime at Hole Charlie is more like that at Hole Baker or Hole Dog. It is hoped that this question will be resolved in the more comprehensive treatment of the entire problem which is now in progress.

A careful examination and comparison of the equilibrium profiles of Holes Able and Charlie should show the thermal anomaly produced in Hole Able by the lagoon, and might give an idea of the age of the lagoon. In such a study the average depth and configuration of the lagoon should be known, for should the lagoon freeze completely each winter, the thermal disturbance would be considerably less than if it did not. If sufficient data are available, the problem will be investigated to provide additional information concerning the shoreline history of the area.

Distribution of permafrost

Thickness of permafrost in lower Ogotoruk Creek valley varies from

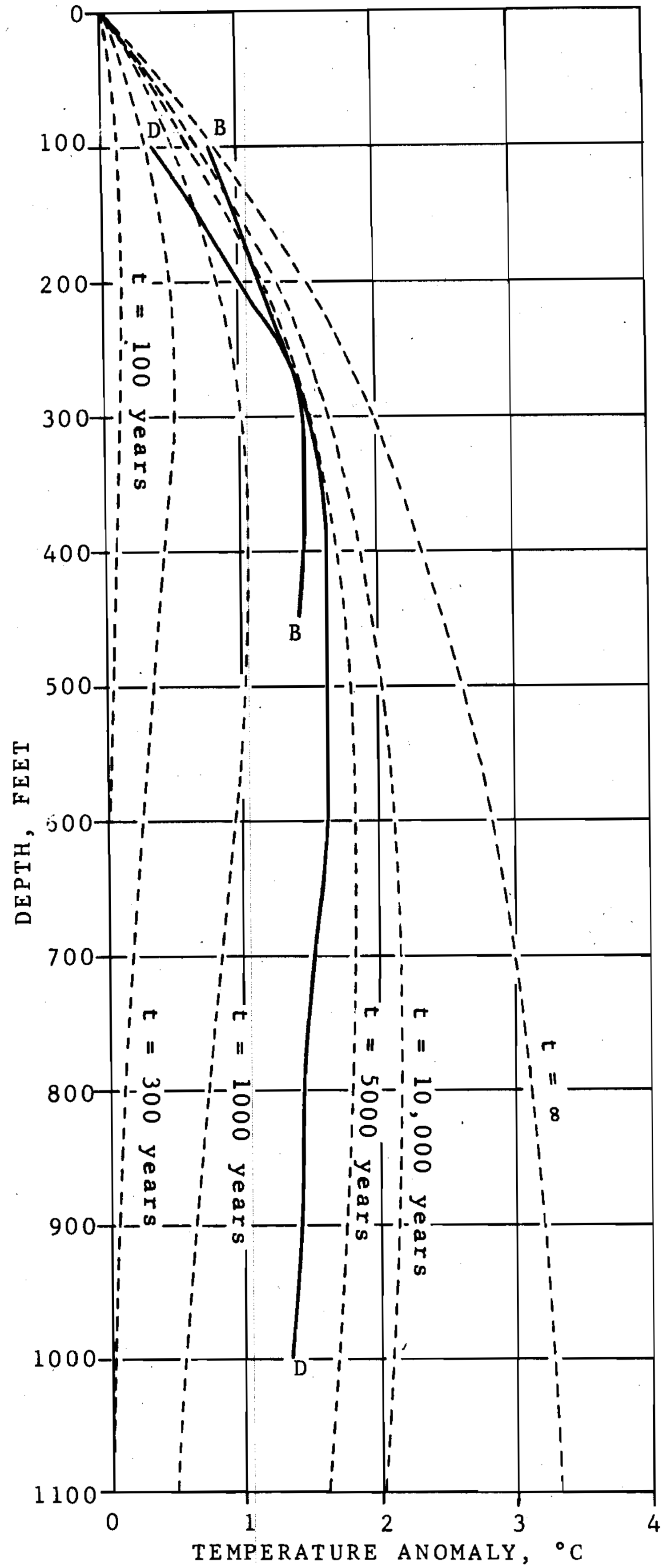

Figure 12. Comparison of theoretical and measured values of temperature anomaly caused by the ocean at Hole Charlie. Solid curves represent difference in temperature between Holes Charlie and Baker (B) and Holes Charlie and Dog (D).

approximately 1,170 feet at Hole Dog to approximately 945 feet at Holes Able and Charlie near the shore. In general, for points inland permafrost thickness can be expected to be close to the value found at Dog.

Permafrost thickness at Holes Able and Charlie is about 300 feet greater than would be expected had the shoreline remained in its present location for 10,000 years or more. It is clear that permafrost still exists at depth beneath the margin of this portion of the Chukchi Sea.

The permafrost thickness is out of equilibrium with the present climate as well as with the present shoreline position. If the existing climate obtained indefinitely, permafrost thickness at Hole Dog would ultimately decrease about 350 feet.

Active layer and shallow permafrost studies

As previously noted, provisions have been made to obtain temperatures between depths of 5 and 90 feet at Holes Charlie and Dog by weekly thermistor readings. From these observations the mean annual temperatures will be calculated so that effects of concurrent climatic change and recent changes in vegetation cover can be studied.

Thermographs installed at Holes Charlie and Dog are providing continuous temperature measurements in the air 4 feet above the ground, at the ground surface, and at the base of the active layer. The present surface temperatures and microclimatic differences between the two holes will be measured by these instruments.

The first thermograph records showed that the active layer was refrozen by the first week of November.

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PRELIMINARY RESULTS OF GRAVITY MEASUREMENTS BETWEEN KOTZEBUE AND POINT HOPE, ALASKA

by

David F. Barnes and Rex V. Allen

Introduction

Other than 3 days of logistic support, no gravity field work was financed by the Atomic Energy Commission at the Chariot test site for 1960. However, the Geological Survey began a reconnaissance gravity survey of northern Alaska during the month of July, and as part of this survey, R. V. Allen spent three days at the Chariot site and one at Kotzebue. His work was planned to show whether the structures being studied by the geologists were associated with gravity anomalies which might aid in their interpretation. Using plane, boat, and weasel transportation he obtained over 60 stations, most of which were located along the coastline between Kotzebue and Point Hope. The results of this survey have influenced the interpretation of some geologic features and may also be valuable for interpreting seismic data from future blasts. However, the gravity data are very limited, and only a preliminary summary is possible in this report.

Since the major geologic structures near Cape Thompson strike northeast, or nearly perpendicular to the coast, the main gravity profile was run parallel to the coastline. The station spacing varied from $\frac{1}{2}$ mile to 10 miles, depending on proximity to Ogotoruk Creek and on availability of float-plane landing sites. A few stations were also made at inland points which could be reached by weasel or float-plane.

Gravity measurements were made with a portable World-Wide meter having a scale-constant of 0.242 milligals per scale division. Drift control was maintained by returning to base stations at intervals of not more than 7 hours. Observed gravity values were established by ties to University of Wisconsin stations (Thiel and others, 1958) at Kotzebue, Point Barrow, and Kivalina. All observed gravities should be accurate to within ± 0.4 mgal. Most stations were close enough to the coast to use sea level for elevation control, but the elevations of inland stations were obtained by single-base altimetry. Simple Bouguer anomalies were computed by using a density of 2.67. No terrain corrections have been applied, but they were computed through zone L (Swick, 1942) for a few stations. Most were less than 0.3 mgal and none exceeded 1.5 mgals.

Results

Figure 13 is a map and adjoining graph showing both the locations and simple Bouguer anomalies of the stations located along the coastline. The locations and gravity values of a few interior stations and the location of a detailed (half-mile station interval) profile are also shown. The gravity data show a broad, uneven low with double minimums near Cape Seppings and Kivalina. The anomaly appears to have a total magnitude of about 30 mgals. However, the profile was not made along a straight line and at least some of this variation may be caused by gravity gradients normal to the general trend of the profile.

No profiles were made normal to the coastline because no gravity gradients were expected parallel to the geologic strike. However, places where inland and coastline profiles overlap clearly show a gradient of about 1 mgal/mile positive towards the Chukchi Sea. In many places the gradient parallel to the geologic strike is greater than gradients across major faults and folds. The small gradients associated with the geologic structures were not unexpected because the density contrasts between the formations cropping

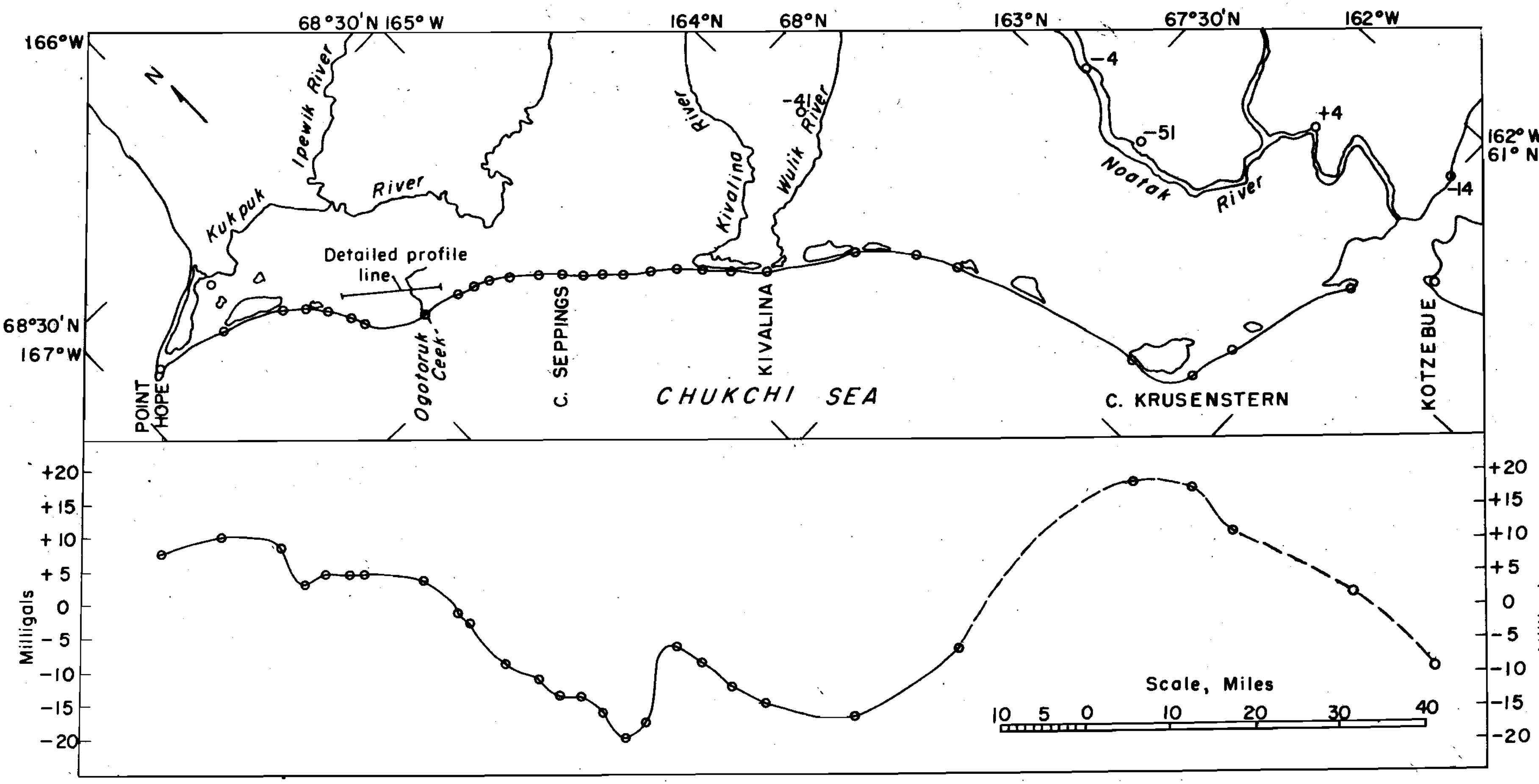

Figure 13.--Simple Bouguer gravity anomalies along Alaskan Coast between Point Hope and Kotzebue

out near Ogotoruk Creek are small. Laboratory measurements of the specific gravity of a dozen hand specimens of various rock types did not vary by more than 0.17 and averaged about 2.7. The positive gradient towards Kotzebue Sound is, however, somewhat surprising. Not only is it parallel to the strike of the geologic structure but it suggests that gravity values beneath the Chukchi Sea may be higher than under other shallow continental seas. The gradient normal to the coastline must indicate deep geologic structure, but additional gravity data on both land and sea are required to determine its significance.

The gradient normal to the coastline reduces but does not eliminate the gravity low indicated by the coastline profile near Cape Seppings and Kivalina. This low is believed to be associated with a thick accumulation of Mesozoic sediments and is similar to the gravity low found further eastward in the area occupied by the Colville geosyncline in Naval Petroleum Reserve No. 4.

Figure 14 shows a map summarizing most of the gravity data now available for northern Alaska. The only area with a large station density is the Naval Petroleum Reserve (Woolson, 1953) where 10 milligal gravity contours are shown. Stations obtained by the University of Wisconsin and by the Geological Survey are shown with circles and with numerals indicating simple Bouguer anomaly values. The University of Wisconsin stations are indicated as solid circles. No contours can be drawn with the limited gravity data now available outside the Petroleum Reserve, but the general form of the gravity field is indicated.

The Colville geosyncline is associated with a broad irregular gravity low of -20 to -30 mgals, which is separated from the Brooks Range gravity low of -70 to -90 mgals by one or more gravity highs that include values as

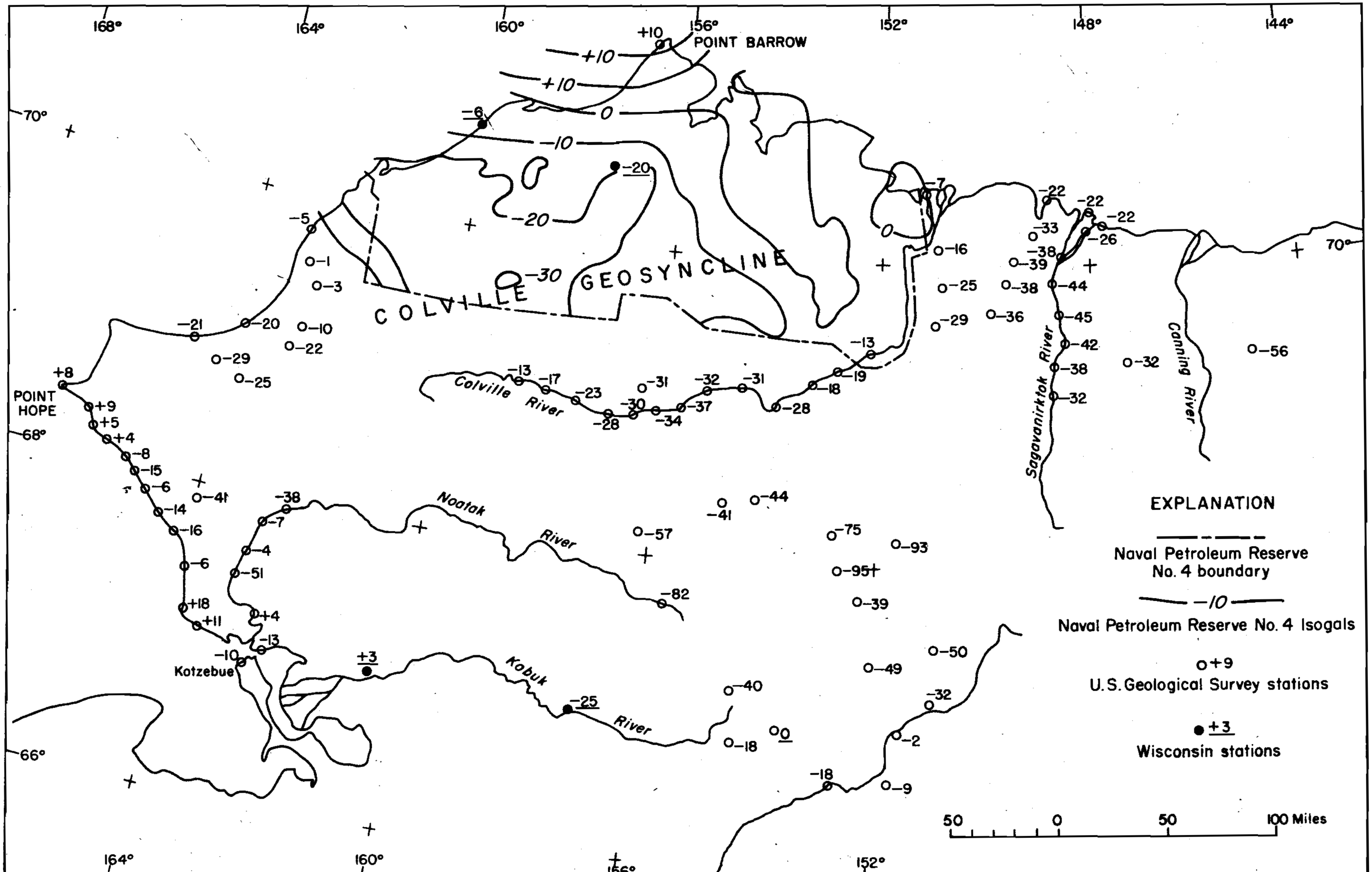

Figure 14.--Simple Bouguer gravity anomalies in northern Alaska

high as -13 mgals. The general trend of the Brooks Range low is slightly south of west so that it probably does not intersect the coastline between Kotzebue and Point Hope. The Colville low is probably complex and may intersect the coastline at several places between Point Barrow and Kotzebue. Gravity highs seem to be associated with Point Barrow and Point Hope, and surficial geology and seismic data from the Petroleum Reserve (Woolson, 1953) indicate that these are also areas where Paleozoic basement rocks are at or close to the surface. The gravity values near Cape Seppings and Kivalina are not as low as those associated with the Colville low southwest of Barrow, and this comparison suggests a thinner sedimentary section on the western end of the Colville geosyncline. However, a quantitative estimate of sediment thickness is not justified without more density data.

The coastline gravity low is broken by a rise of more than 10 mgals southeast of Cape Seppings. This rise results from basic intrusives which crop out northeast of Kivalina, and which are shown by aeromagnetic traverses to extend westward toward the gravity high. The form of the gravity high suggests a steeper dip for the northern edge of these intrusives than for the southern edge.

Gravity gradients on either flank of the coastline low are generally gentle and do not indicate major marginal faults or major increases in sediment thickness within a short distance. A detailed profile across the valley of Ogotoruk Creek and across the steeply dipping geologic faults and folds on its northern edge showed no significant variation in gravity. A few observed lows and highs of 1 to 2 mgals can probably be explained by possible errors in altimetry, and only one 1.5 mgal low over the Triassic outcrop on the north side of Ogotoruk valley (plate 1) correlates clearly with geologic mapping. The gravity data suggest that the sediment thickness increases gradually southeast of Ogotoruk Creek and that the faults northwest of the creek displace a relatively shallow sequence. However, the density contrasts are not large, and the gravity data may provide a poor indication of geologic structure.

Large variations in gravity were observed along the Noatak River. These may be related either to intrusives or to pronounced changes in sediment thickness. A reliable interpretation of this area cannot be made without additional gravity data.

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GROUND-WATER INVESTIGATIONS IN SUPPORT OF PROJECT CHARIOT

PHASE III--SUMMER 1960

by

Roger M. Waller

Introduction

Ground-water investigations for Project Chariot were continued in the Cape Thompson area, Alaska (fig. 15) during the summer of 1960. Brief field studies were made to further the knowledge of potential ground-water contamination, the ground-water regimen in the Ogotoruk Creek valley, and the occurrence and source of recharge to springs in the general area. The latter two studies represent investigations of shallow aquifers and deep aquifers, respectively, in this permafrost region. Particular attention is being given to sources of potable water in the vicinity of the Chariot test site for use after the proposed test shot.

Shallow aquifers

The shallow aquifers, as considered in the Project Chariot studies, are denoted as those water-bearing horizons immediately beneath and adjacent to streams, which may or may not contain water throughout the year. The presence of permafrost precludes the occurrence of any appreciable thickness of water-saturated sediments in the weathered mantle overlying bedrock in the areas away from streams or large bodies of water. Hence, in this area, shallow aquifers are associated with streams only. Water from such aquifers is usually expected to be low in dissolved solids, whereas an appreciable amount of dissolved solids is indicative of water contributed from a deep aquifer.

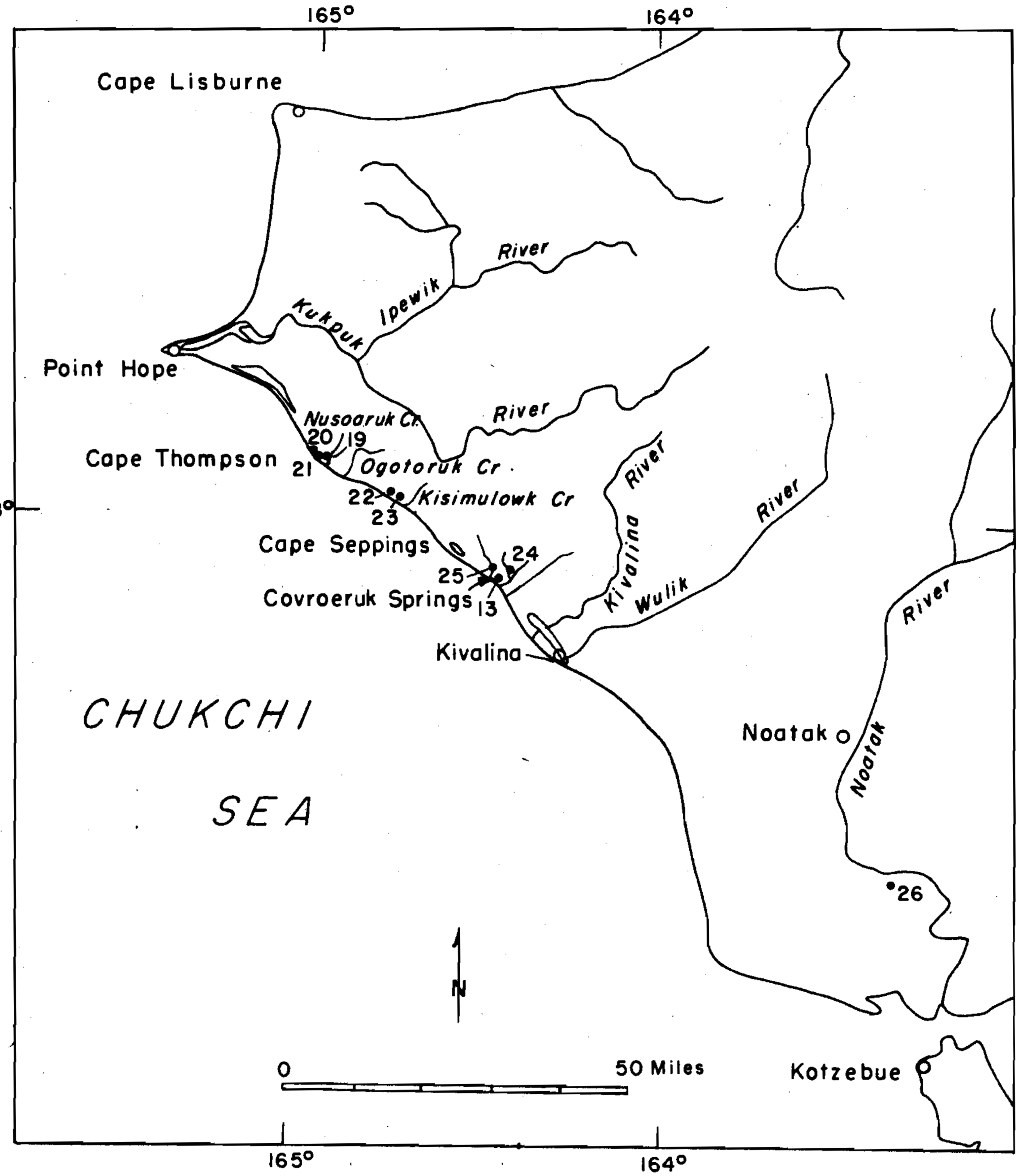

Figure 15.--Map of Northwestern Alaska showing locations of 1960 water-sample collection sites

Ogotoruk Creek valley

Observations were continued on the shallow aquifer (Kachadoorian and others, 1960a, p. 74) in the flood-plain deposits of the lower reach of Ogotoruk Creek (fig. 15). The water table in the flood plain responds rapidly, as would be expected, to changes in the flow of Ogotoruk Creek.

The aquifer was recharged several times by creek water during the spring and summer of 1960. A "flood" on August 10, 1960, inundated the flood plain and presented an opportunity to observe an appreciable rise in the water table. The rapid rise in the water table paralleled the rapid increase in discharge of Ogotoruk Creek. A rising water table, concurrent with a rising creek stage, indicates a high permeability in the flood-plain deposits. It is hoped that some measurements of the rate and extent of the declining water table may be obtained as the creek diminishes in flow during the winter.

The thickness of the flood-plain deposits has not been determined. Excavations planned for the spring of 1960 were thwarted by an earlier than anticipated spring breakup of the creek. Such excavations will be attempted in the early winter of 1960, or prior to the 1961 breakup, to determine whether the shallow aquifer exists the year around. Results should show the feasibility of establishing a well supply for the use of Chariot camp.

Adjacent valleys

Kisimulowk Creek and Kukpuk River (fig. 15) are the two streams nearest to the Chariot site having shallow aquifers that can be considered for water supplies. The Kukpuk River probably maintains a flow the year around, whereas Kisimulowk Creek has a regimen similar to that of Ogotoruk Creek. Observations on Ogotoruk Creek should be applicable to Kisimulowk Creek. Verification of year-round flow in the Kukpuk River is planned for the 1960-61 winter.

Source of recharge

The shallow aquifers in the Cape Thompson area receive their principal recharge from streamflow resulting from rainfall and snowmelt. In addition, some recharge may be derived from springs or ground-water seepage, feeding directly into the aquifer or indirectly into the upstream tributaries of the stream. Consequently, during the winter the aquifers having no ground-water inflow gradually drain and may become dry and completely frozen by late winter.

The greatest recharge apparently occurs at the spring breakup when the melt water percolates into the "dewatered" aquifers. The melt water thaws the frozen alluvium and gradually fills all the pore spaces that had drained during the preceding winter. Subsequent summer precipitation increases the streamflow and again recharges the aquifers during the high-water stages. At low-water stages the aquifers are actually discharging ground-water flow to the stream. Hence, as winter approaches and surface-water recharge diminishes, the aquifers gradually are depleted as the water drains into the creek and later flows to the sea as subsurface water.

Deep aquifers

Deep aquifers in this study are those considered to occur within the consolidated rock, or bedrock, of the area and below or within the frozen segment of the rock. In the previous studies (Kachadoorian and others, 1960a, 1960b), several springs were noted which were thought to indicate deep aquifers because of the high mineral content of the water and their sustained flow through the winter. The origin of the waters that supply these springs is of primary concern in the Project Chariot study of the ground-water regimen. Deep aquifers can be widespread and may receive their recharge from areas many miles from their point of discharge. Brief investigations were made in 1960 to determine possible areas of recharge to the springs.

Chariot site vicinity

Within the vicinity of the Chariot test site, evidence of deep aquifers was suggested by the chemical analysis (Kachadoorian and others, 1960a, table 11) of Nusoaruk Creek (fig. 15) water. Additional analyses (table 4) of water samples taken from different sources this year further indicate a ground-water source nearby. Sample No. 19 is from a spring flowing at the base of a cliff. The water may have been contaminated by sea water; therefore, another sample is to be taken for confirmation and correlation with that of Nusoaruk Creek. A chemical analysis (No. 20, table 4) also was made on water from nearby Emmikroak Creek (fig. 15) at low flow. The analysis does not indicate a deep ground-water source.

Partial analyses of samples of several other small streams near the test site also are given in table 4 (see locations on fig. 15). No evidence of a deep ground-water source is indicated.

Covroeruk Springs

Several days in August were spent making observations at Covroeruk Springs (fig. 15). Discharge measurements, water temperatures, and water samples were taken to delineate further the hydrology of the springs. Figure 16 shows the discharge of the springs in relation to the specific conductance, dissolved solids, chloride, and sodium content of the water for the dates of observation. The graphs show that the mineral content of the water varies directly with the discharge. In contrast, streams usually have an inverse relation between mineral content and discharge. The variation of mineral content of Covroeruk Springs may be related to various sources of recharge, to transmission of water through a greater thickness of material at high discharge, to dilution by streams at low discharge, to combinations of the above, or to other, unknown factors.

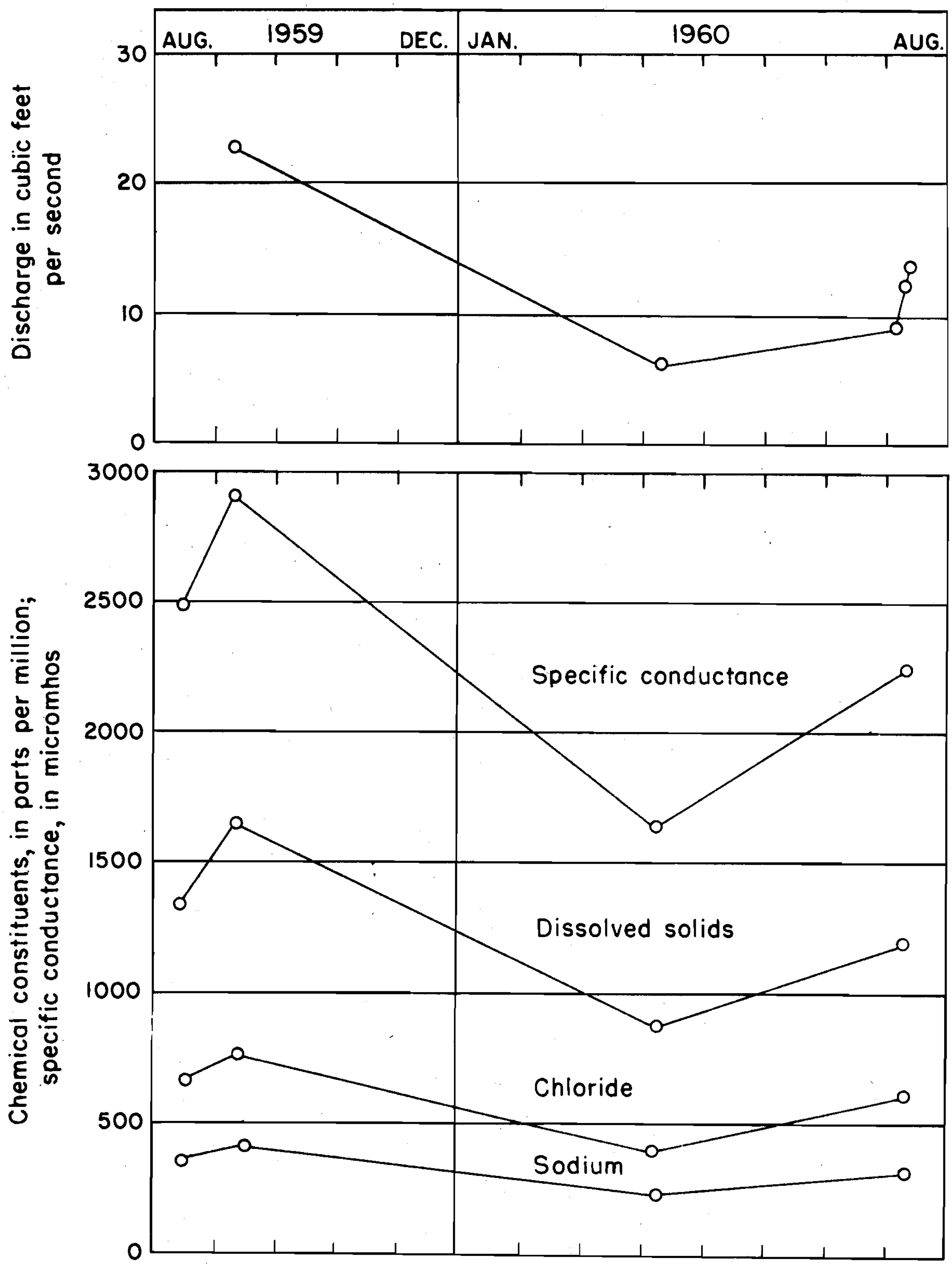

Figure 16.--Change in chemical quality of Covroeruk Springs water with change in discharge, 1959-1960

Table 4.--Chemical composition of water in northwestern Alaska
Analytical results in parts per million except as indicated

Number on figure 15	13		19	20	21
Source	Covroeruk Springs			Emmikroak Creek	Creek
Date of collection	4/9/60	8/6/60	6/5/60	8/4/60	8/4/60
Discharge (cubic feet per second)	6.17	12.3	-	1/0.04	1/0.11
Silica (SiO_2)...................	4.9	4.5	5.3	2.6	4.1
Iron (Fe).......................	2/0.00	2/0.03	0.00	0.00	0.00
Manganese (Mn)..................	0.00	0.01	0.00	0.00	0.00
Calcium (Ca)....................	53	58	164	43	43
Magnesium (Mg)..................	35	56	313	7.6	16
Sodium (Na).....................	228	310	2860	3.7	6.1
Potassium (K)...................	10	12	116	0.3	0.9
Bicarbonate (HCO_3)..............	164	161	293	151	158
Carbonate (CO_3)................					
Sulfate (SO_4)..................	73	76	542	18	43
Chloride (Cl)...................	400	605	4880	6.0	9.5
Fluoride (F)....................	0.0	0.2	0.4	0.2	0.1
Nitrate (NO_3)..................	0.3	0.0	0.0	0.2	1.2
Nitrate (NO_2)..................	0.00	-	-	-	-
Phosphate (PO_4)................	0.00	-	-	-	-
Dissolved solids					
Calculated..................	885	1200	9020	156	202
Residue on evaporation at 180°C	-	-	-	-	-
Hardness as $CaCO_3$...............	276	374	1700	138	173
Noncarbonate hardness as $CaCO_3$..	142	242	1460	14	44
Alkalinity as $CaCO_3$.............	-	-	-	-	-
Specific conductance............ (micromhos at 25°C)	1640	2250	14500	274	341
pH..............................	7.9	7.9	7.1	7.5	7.6
Color...........................	5	0	10	0	0

1/ Estimated
2/ In solution when analyzed
13. 9 miles SE of Cape Springs, Alaska (approx. 63°53'N., 164°53' W.)
19. 3.5 miles SE of Cape Thompson, Alaska (approx. 68°07' N., 165°52' W.)
20. 200 feet above mouth and 1.5 miles SE of Cape Thompson, Alaska (approx. 68°07' N., 165°52' W.)
21. 400 feet above mouth and 2.5 miles SE Cape Thompson, Alaska (approx. 68°07' N., 165°52' W.)

Table 4.--Chemical composition of water in northwestern Alaska--(Cont.)
Analytical results in parts per million except as indicated

Number on figure 15 / Source	22 Creek	23 Creek	24 W. trib. of Oakpissoorook R.	25 Tutteegea River	26 Spring
Date of collection	8/7/60	8/7/60	8/6/60	8/7/60	4/9/60
Discharge (cubic feet per second)	1/ 0.11	1/ 0.01	4.93	1/ 1.5	1/ 6
Silica (SiO_2)	4.3	3.6	4.5	-	7.0
Iron (Fe)	2/ 0.00	-	0.03	-	0.00
Manganese (Mn)	0.00	-	0.00	-	0.01
Calcium (Ca)	-	-	62	23	40
Magnesium (Mg)	-	-	26	11	17
Sodium (Na)	16	4.2	142	-	9.8
Potassium (K)	1.4	.3	2.3	-	0.4
Bicarbonate (HCO_3)	-	-	167	222	180
Carbonate (CO_3)					
Sulfate (SO_4)	-	-	9.5	-	15
Chloride (Cl)	-	-	320	-	20
Fluoride (F)	-	-	0.1	-	0.3
Nitrate (NO_3)	-	-	0.6	-	0.4
Nitrite (NO_2)	-	-	-	-	0.00
Phosphate (PO_4)	-	-	-	-	0.00
Dissolved solids					
Calculated	-	-	646	-	199
Residue on evaporation at 180°C	-	-	-	-	-
Hardness as $CaCO_3$	56	28	263	102	170
Noncarbonate hardness as $CaCO_3$	-	-	124	-	22
Alkalinity as $CaCO_3$	-	-	-	-	-
Specific conductance (micromhos at 25°C)	166	36	1220	381	342
pH	6.8	7.2	8.0	7.8	7.8
Color	5	0	5	0	0

1/ Estimated
2/ In solution when analyzed
22. 200 feet above mouth and 4.3 miles SE of Ogotoruk Creek, Alaska (approx. 68°04' N., 165°35' W.)
23. 200 feet above mouth and 4.5 miles SE of Ogotoruk Creek, Alaska (approx. 68°04' N., 165°35' W.)
24. 1 mile upstream from confluence with Oakpissoorook River and 9 miles SE of Cape Seppings, Alaska (approx. 67°53' N., 164°52' W.)
25. 1 mile above mouth and 8 miles SE of Cape Seppings, Alaska (approx. 67°53' N., 164°55' W.)
26. 35 miles south of Noatak and 100 feet from confluence with Noatak River (approx. 67°15' N., 162°50' W.)

On the stream draining Covroeruk Springs, hourly measurements for a 48-hour period were taken on a temporary staff gage. Figure 17 shows the gage-height vs. time and the discharge measured during the period. The discharge of the springs increased by about 50 percent during this period. Of further interest is the periodic rise and fall of the stream stage superimposed on the increasing stage or discharge. The high and low phases are about 6 hours apart and probably represent a tidal effect. Wells tapping artesian aquifers, and springs representing an outflow from confined aquifers, commonly respond to earth and sea tidal effects and atmospheric pressure. This effect, as observed on the Covroeruk Springs discharge, indicates that the water is coming from a confined aquifer. The confinement may be due to the perennially frozen segment of the earth, to impermeable bedrock formations, or both. The periodic rise and fall of the discharge represents loading and unloading on the confining bed, or subocean outlet of the aquifer, by the ocean. Similarly, atmospheric pressure changes result in variations of water level. However, the high atmospheric pressure increase (fig. 17) did not reflect a decreasing discharge as was expected. The opposite effect was observed and is not fully understood.

The increase in discharge of Covroeruk Springs seems anamolous at a time when Ogotoruk Creek and, presumably, all other streams in the general area were gradually diminishing in flow due to very little precipitation in the preceding weeks. However, the increasing flow of the springs in the recharge area may be attributed to the effects of the spring runoff or the last heavy rainfall in late June. The subsurface transmission of this effect could lag by days, weeks, or months.

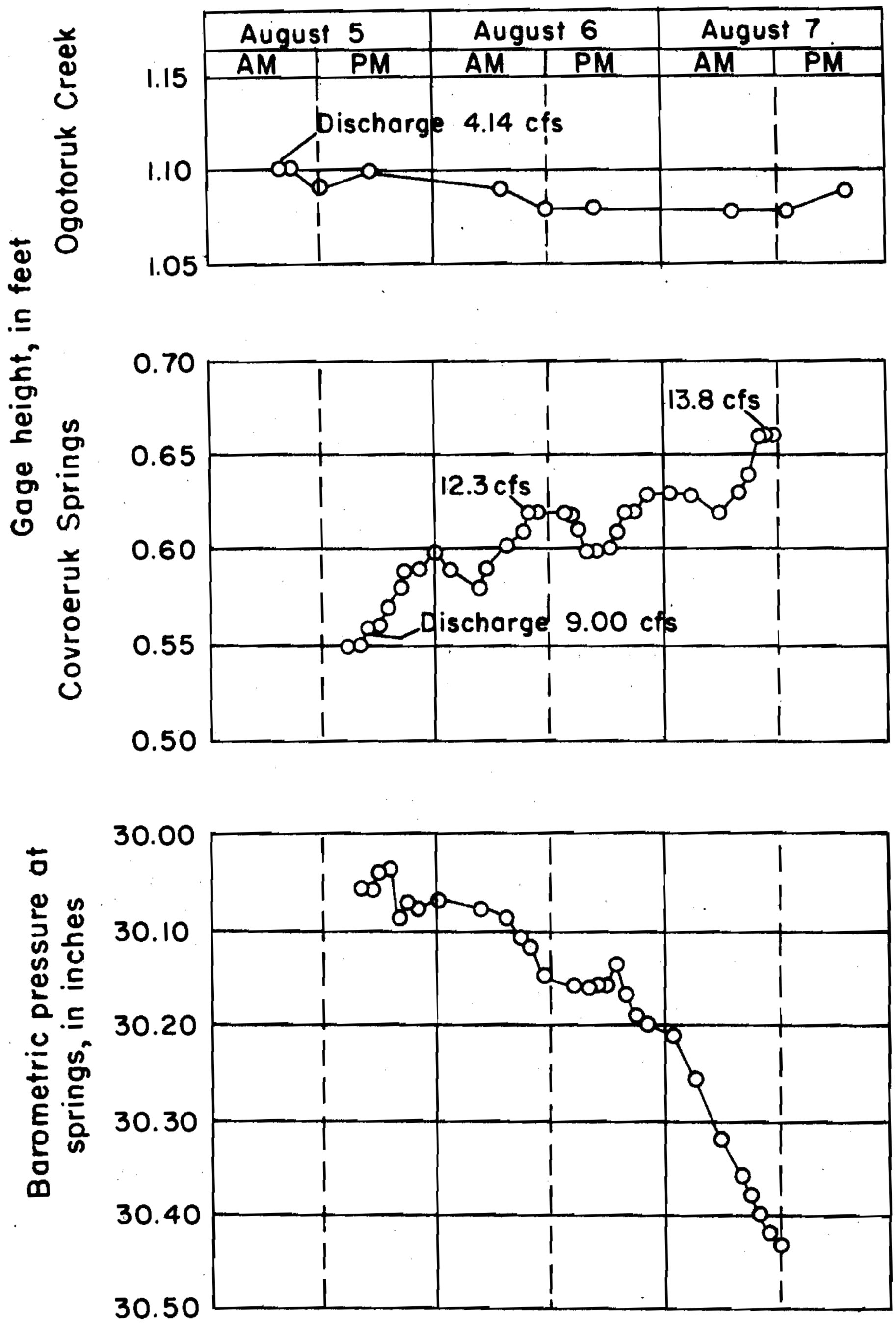

Figure 17.--Stage of Ogotoruk Creek and Covroeruk Springs streamflow in relation to barometric pressure, August 5-7, 1960

The chemical analyses of Covroeruk Springs (No. 13, table 4) water taken in April and August of 1960 are shown in table 4. A chemical analysis (No. 24, table 4) of water from the west tributary of the Oakpissoorook River (fig. 15) was determined for correlation with Covroeruk Springs water. The analyses are similar in that the tributary stream has about half the mineral concentration of the springs. These data suggest the possibility that the stream is the source of recharge for Covroeruk Springs. Moreover, the stream flows across the strike of the rocks, which probably extend to the springs. The stream is at a higher elevation than the springs and, at the time of observation during a low stage of the stream, the flow sank into the stream bed behind a hill from the springs. However, if the stream were recharging the springs, it appears unlikely that the water from the springs would have the increased concentration of minerals. The discharge of the stream on August 6 was about half that of Covroeruk Springs.

Table 4 shows an analysis (No. 25) of water from Tutteegea River (fig. 15), which was taken at low flow to determine whether ground water was contributing to the low flow. It apparently represents only surface-water runoff. The analysis of the spring referred to in an earlier report (Kachadoorian and others, 1960b, p. 30) also is presented in this report (No. 26, table 4 and fig. 15).

Sources of recharge

The deep aquifers in the area of investigation receive recharge from rainfall and seepage from streams in the outcrop areas. The occurrence of permafrost to depths of about 1,170 feet (see chapter on geothermal studies) in this region creates an obstacle to ground-water movement from recharge to discharge areas. In order for ground water to move from an area of recharge to an area of discharge, the water must pass through or under the permafrost. To pass through the permafrost, the water must have sufficient velocity, heat, or mineral content so that it will not freeze before reaching a point of discharge. If the ground water is transmitted beneath the permafrost, the same general conditions must prevail to permit travel downward from the recharge point and upward through the permafrost to a discharge point. Data and observations on discharge, chemical quality, and temperature of the water provide the basis for postulating sources of recharge.

In the area northwest of Ogotoruk Creek, the deep aquifers have two probable sources of recharge. The steeply dipping rocks forming the hills provide a catchment area for snowmelt and rainfall. Water may percolate through unfrozen rock fractures and emerge in streams or springs. The second possible source of recharge in this area is the Kukpuk River to the north (fig. 15). The river traverses the same rock formations, although at not too great an elevation above the springs, and may lose water into the rocks. Because of the few small springs and the small low-flow stream discharge observed in this area, snowmelt and rainfall probably are the principal sources of recharge.

In the area southeast of Ogotoruk Creek, recharge to deep aquifers probably occurs along the Kukpuk River and the upper reaches of the Kivalina River. An aerial reconnaissance was made in this area at a time of low stream flow. Stream losses at specific sites were not determined, but the brief reconnaissance and discussions with other geologists making field investigations in the area, indicate that certain rock formations along the streams are susceptible to river infiltration. Hence, water could percolate through the permeable portions of the rocks and emerge in springs and contribute to the flow of streams along the coast.

Conclusions

Tentative conclusions of the investigations to date are presented herein for the two major goals of the ground-water phase of Project Chariot.

Radioactive debris falling in the Ogotoruk Creek drainage area could contaminate the shallow alluvial aquifer of Ogotoruk Creek. However, the aquifer probably is nearly depleted and replenished each year. The portion of water or ice that is retained in the sand and gravel each year probably is flushed out the following year, except possibly for a wedge below sea level near the lagoon at the mouth. Whether this wedge is, or can be, flushed out each year is not known. It might provide a reservoir for accumulating the radioactivity in ground water after the test shot.

Any local concentration of radioactive debris occurring inland on recharge areas could contaminate the deep aquifers. The aquifers could be contaminated by subsequent recharge of snowmelt or rain water percolating into the rocks. In addition, contamination of deep aquifers could result from local concentrations of radioactive debris in the upper reaches of the Kukpuk and Kivalina river watersheds. Radioactivity could be concentrated in some recharge areas by drifting snow accumulating in sheltered areas, if the nuclear devices are detonated during the spring. Runoff and the subsequent postulated recharge along the rivers could carry the radioactivity into the deep aquifers and coastal springs. Both the Kukpuk and Kivalina rivers enter lagoons at Point Hope and Kivalina villages, respectively (fig. 15). Whether dilution in the aquifers and streams would reduce any local concentrations of radioactivity to safe limits is not known.

The town of Point Hope uses a well in the summer for water supply. The aquifer probably is recharged by snowmelt and rainfall directly on the beach. During the winter the town obtains its water from snow and from ice cut from nearby lakes. Kotzebue and Cape Lisburne (fig. 15) are the nearest settlements having subsurface sources of water supply. The sources of recharge for Kotzebue and Cape Lisburne probably are more than 50 miles from the Chariot test site.

References cited

Kachadoorian, Reuben, and others, 1960a, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska--preliminary report: U. S. Geol. Survey TEI-753, 94 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

__________ 1960b, Supplemental report on geologic investigations in support of Phase II, Project Chariot in the vicinity of Cape Thompson, northwestern Alaska: U. S. Geol. Survey TEI-764, 30 p.; also U. S. Geol. Survey open-file report.

SURFACE WATER DISCHARGE OF OGOTORUK CREEK NEAR CAPE THOMPSON, ALASKA

by

Marvin J. Slaughter

Introduction

Ogotoruk Creek empties into the Chukchi Sea approximately 6-1/2 miles southeast of Cape Thompson, Alaska. The stream is about 10 miles long, braided throughout most of its length, and drains approximately 40 square miles.

Hydrology

The gaging station (officially named Ogotoruk Creek near Cape Thompson, Alaska) on Ogotoruk Creek is located 1.2 miles above the mouth. The station is not operated during winter months because severe ice conditions results in little or no flow.

During the 1960 water year (October 1, 1959 to September 30, 1960) no significant flow occurred from late October 1959 to mid-May 1960. When the site was visited on November 11, 1959 and on April 7, 1960, there was no flow in the creek. A tabulation of daily and monthly mean discharges and peak discharges that exceeded 400 cfs (cubic feet per second) are shown on table 5 for the 1960 water year.

Only one discharge exceeded the base for peaks (400 cfs) during the 1960 water year. The surface runoff in water year 1960 was substantially less than in water year 1959. The observed runoff during water year 1959

Table 5.--Discharge in cubic feet per second of Ogotoruk Creek near Point Hope, Alaska from October 1, 1959 to September 30, 1960

Day	October	May	June	July	August	September
1	56		22	43	5	30
2	59		40	39	4	24
3	53		69	29	4	19
4	51		76	20	4	16
5	56		71	16	1/ 4	14
6	48		98	13	4	12
7	1/ 45		104	12	1/ 4	11
8	40		101	12	3	10
9	31		85	12	10	9
10	23		76	12	400	8
11	17		60	23	308	8
12		2/ 9	43	38	93	8
13			48	30	50	1/ 7
14			40	25	30	5
15			43	19	20	5
16			36	15	16	6
17			32	13	14	5
18			27	11	11	5
19			23	10	9	4
20	2/ 4		26	10	8	4
21			29	9	7	2/ 4
22			24	8	7	2/ 3
23			20	7	7	2/ 3
24		109	28	5	7	2/ 3
25		1/ 95	33	5	10	2/ 3
26		93	55	4	85	2/ 2
27		98	160	4	118	2
28		80	82	6	98	2
29		55	53	12	62	2
30		36	42	9	85	2
31		22		7	36	
Total, cfsd	559	792	1,646	477	1,523	236
Mean, cfs	18.0	25.6	54.9	15.4	49.1	7.87
Ac-ft	1,110	1,580	3,260	946	3,020	468

Peak discharge (base, 400 cfs).--Aug. 10, 5 p.m., 940 cfs (3.59 ft.).

1/ Discharge measurement made on this day.
2/ No gage-height record; discharge estimated on basis of weather records.

Note.--Stage-discharge relation affected by ice Oct. 9-11, Sept. 9-12, 15-20, 27-30, and during most of the periods of no gage-height record.

was: June, 12,660 acre-feet; July, 7,080 acre-feet; August, 1,580 acre-feet; and September, 787 acre-feet (Kachadoorian and others, 1960a).

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Kachadoorian, Reuben, and others, 1960a, Geologic investigation in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska--preliminary report: U. S. Geol. Survey TEI-753, 94 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

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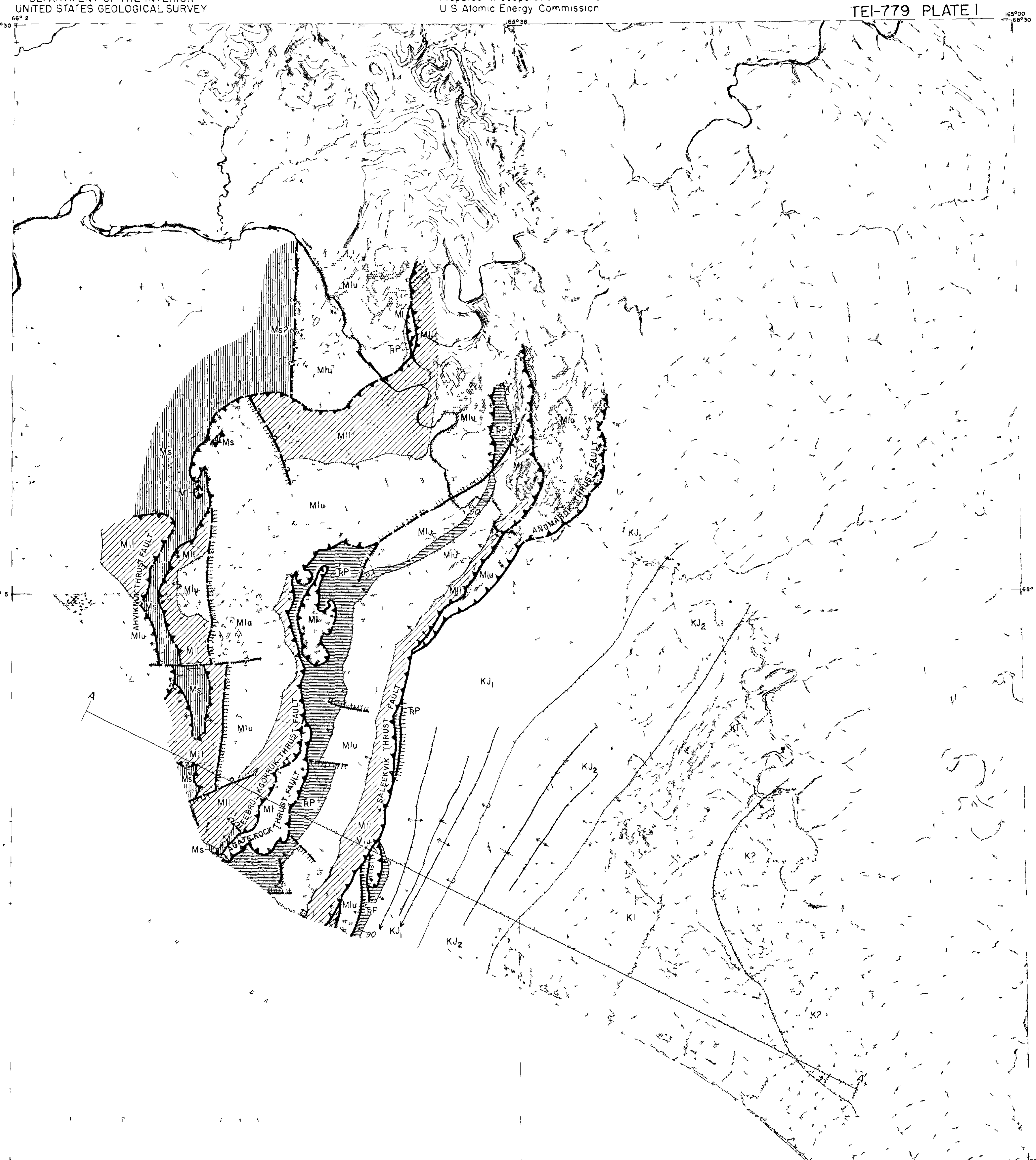
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

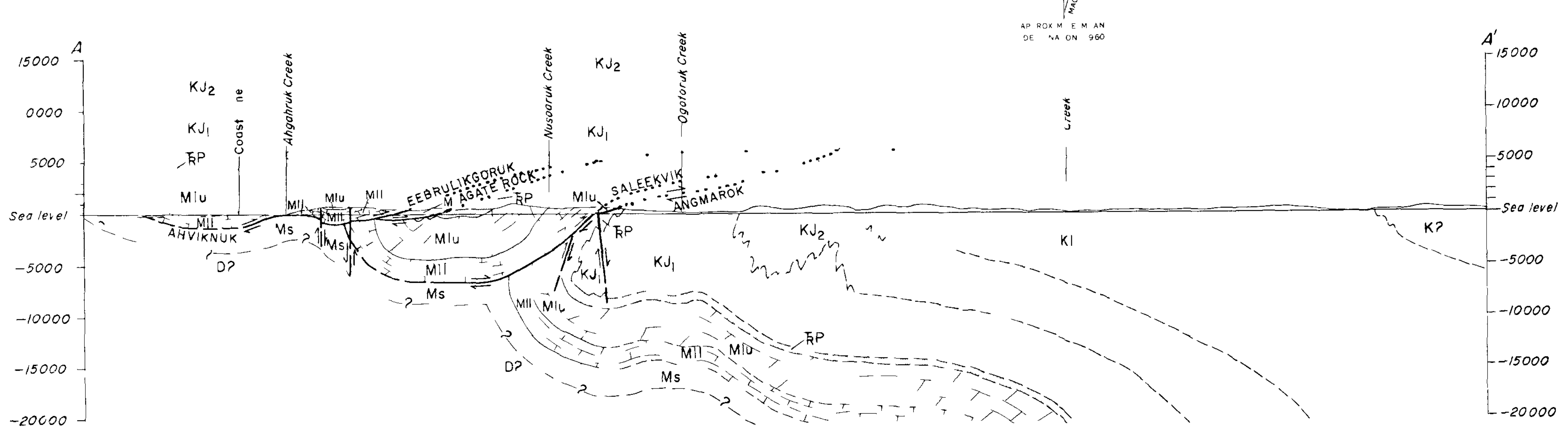
Prepared in cooperation with the
U S Atomic Energy Commission

TEI-779 PLATE I



Base from U S Geological Survey Point Hope A-2 quadrangle and U S Army Map Service Point Hope A 1, B 1 and B 2 advance quadrangles

Geology by R H Campbell, R Kachadoorian, C L Sainsbury and D W Scholl, 1958, R H Campbell and D R Currey 1959 and 1960



SECTION ALONG A-A'

GENERALIZED GEOLOGIC MAP AND STRUCTURE SECTION OF THE AREA OF THE PROJECT CHARIOT TEST SITE

By
R H Campbell

0 1 2 3 4 5 6 7 8 9 10 Miles

Contour interval 50 feet
Dashed lines represent 25 foot contours
Datum is mean sea level

1960

EXPLANATION

Sedimentary rocks

CRETACEOUS(?)

K?

Mudstone-sandstone unit of probable Cretaceous age

CRETACEOUS — *Lower Cretaceous*

Kl

Mudstone unit with minor sandstone Locally contains Aucella crassicolis

JURASSIC(?) AND CRETACEOUS(?)

KJ_2

Sandstone-mudstone unit

KJ_1

Mudstone-sandstone unit (Tiglukpuk? formation of earlier reports)

PERMIAN AND TRIASSIC

ŦP

Argillite, chert, shale, and limestone of the Siksikpuk and Shublik formations. Locally includes infolded and infaulted segments from the basal part of unit KJ_1

MISSISSIPPIAN — *Lisburne Group*

Ml | Mlu | Mll

Limestone and dolomite, in part the Lisburne group
Mlu, upper part, chiefly light gray dolomite, includes Ml_4 and Ml_5 of Campbell, 1960
Mll, lower part, chiefly dark gray bioclastic limestone with some shale interbeds, includes Ml_1, Ml_2, and Ml_3 of Campbell, 1960
Ml, undifferentiated, in some areas containing both Mlu and Mll

Lower Mississippian

Ms

Sandstone-mudstone unit containing minor amounts of bioclastic limestone

DEVONIAN(?)

D?

Sandstone-mudstone unit, thick-bedded, nonfossiliferous, base not exposed. Shown only on cross section. Exposed at surface west of mapped area

90

Contact, showing vertical attitude and direction of normal and overturned dips, dashed where approximately located

? ?

Fault, showing relative horizontal movement, dashed where approximately located, questioned where probable

? ?

High angle fault, showing direction of dip, hachures on downthrown side Dashed where approximately located, questioned where probable

? ?

Thrust fault, showing dip, saw-teeth on side of upper plate. Dashed where approximately located, questioned where probable

Fault zone

Anticline showing trace of axial plane and bearing of plunging axis. Dashed where approximately located

Syncline showing trace of axial plane. Dashed where approximately located

This map is preliminary and has not been edited or reviewed for conformity with U S Geological Survey standards and nomenclature